Review on Radio Resource Allocation Optimization in LTE/LTE-Advanced using Game Theory

Sanaa Oulaourf, Abdelfatteh Haidine, Abdelhak Aqqal and Hassan Ouahmane

Information Technology Laboratory (ITL), National School of Applied Sciences El Jadida (ENSAJ), University Chouaib Doukkali , El Jadida, Morocco

sanaaoulaourf@gmail.com; a.h.haidine@ieee.org; aqqal.a@ucd.ac.ma; ouahmane.h@ucd.ac.ma

Abstract: Recently, there has been a growing trend toward applying game theory (GT) to various engineering fields in order to solve optimization problems with different competing entities/contributors/players. Researches in the fourth generation (4G) wireless network field also exploited this advanced theory to overcome long-term evolution (LTE) challenges such as resource allocation, which is one of the most important research topics. In fact, an efficient design of resource allocation schemes is the key to higher performance. However, the standard does not specify the optimization approach to execute the radio resource management and therefore it was left open for studies. This paper presents a survey of the existing game theory based solution for 4G-LTE radio resource allocation problem and its optimization.

Keywords: Game Theory; LTE/LTE-Advanced; 4G; resource allocation; Optimization.

1. Introduction

The continuous increasing users' needs and demands based heterogeneous services and applications led to the development of several variants of Long Term Evolution (LTE) or 4G; namely LTE-Advanced and recently LTE-Advanced Pro technology, as specified in 3GPP (3rd Generation Partnership Project) releases from 8 to 13, but in the same time it exhausts the limited radio resources.

LTE/LTA-A has been designed to fulfil a number of benchmarks including, among others, high peak data rates, high spectral efficiency, low latency, flexible deployment of bandwidth, and all IP network. Moreover, the basic changes in LTE/LTE-A compared to previous 3GPP system are, first, the use of a completely revised air interface based on Orthogonal Frequency Division Multiple Access (OFDMA) in the downlink and SC-FDMA (Single-carrier Frequency Division Multiple Access) in uplink with the possibility of using two duplex modes FDD (frequency division duplex) and TDD (time division duplex) to separate uplink and downlink transmissions between eNodeB and multiple user equipment (UE) [1]. Second, the adoption of flat architecture for the access network by omitting the centralized intelligent controller and distributing the intelligence amongst the base station, eNodeB, in order to ensure fast communication and decision between eNodeB and UE, and to reduce the time required for a handover [2]. Therefore, unlike in the UMTS where the radio resource management (RRM), is located in the controller, in this distributed architecture the RRM is a part of the eNodeB and is the responsible for, among other functions, for determining the type of the required resource control, the required resource sharing, and the assignment methods. Besides the quickly changing radio link quality, the bursty nature of packet data traffic imposes a challenge on the radio resource assignment and requires a dynamic and fast resource allocation [3].
However, the standard does not specify the implementation of the scheduling and resource allocation problem and therefore it was left up to service providers (SP) to deal with it [4]. Furthermore, given the scarcity of resources such as, among others, the frequency spectrum and terminal battery power; SP were compelled and strongly urged to find an optimal solution while guaranteeing a good quality, low costs and a good performance. Therefore, more advanced optimization methods are needed.

On the other hand, in the last few decades, game theory (GT); the mathematical study of strategies and decision-making; has taken a major portion of all research fields regarding the optimization of complex issues. In fact, this discipline considers the behaviour of decision-makers in interactive situations, between rational intelligent entities (players) [5]. Therefore, these features justified its use in Radio Resource allocation problem where users are continuously competing.
The aim of this paper is to present a survey that summarizes the current state of understanding regarding the optimization of LTE/LTE-A resource allocation issue using GT. Thus, the paper is organized in three steps as follows: the second section provides an overview of resource allocation in LTE/LTE-A network. The third section presents a brief definition of GT. While the fourth section discusses some of the existing works to illustrate the efficient use of GT.

2. Resources allocation in 4G

The exponential increase in the consumption of the wireless cellular services and technologies has brought demands for multiple simultaneous access to various application and services, high capacity, high speed, and high data rate, to meet those requirements while guaranteeing a good quality, low costs and a good performance, 3GPP has proposed the LTE specification. Indeed, besides the adoption of an all-Internet Protocol (IP) approach, the major evolution in LTE compared to previous 3GPP wireless systems is the completely revised air interface which was specified to overcome the effects of multipath fading and inter-symbol interference (ISI) [1].
Instead of spreading one signal over the complete carrier bandwidth, LTE combine Orthogonal Frequency Division Multiplexing (OFDM) that transmits the data over many narrowband carriers of 180 kHz each and the associated access schemes, and therefore LTE adopt OFDMA with cyclic prefix (CP) in the downlink direction and SC-FDMA with CP in the uplink direction. Both technologies exploit multiple orthogonal subcarriers, which can be used to take advantage of multiuser diversity [6].
In other hand, dealing also with the assignment of multiple users to a shared communication resource SC-FDMA is used in the uplink wireless transmission in mobile communication systems, where lower peak-to-average power ratio (PAPR) greatly benefits the mobile terminal in terms of transmit power efficiency and reduced cost of the power amplifier [7]. It is also called a linearly pre-coded or coded OFDMA, because it

has an additional Discrete Fourier Transform (DFT) processing step preceding the conventional OFDMA processing. LTE-A (release 10-12) is an enhancement to LTE in term of data rate, spectral efficiency, performance, etc. The main functionalities and some of the significant improvements of LTE-A are:

- Carrier Aggregation (CA)
- Coordinated multipoint transmission and reception (CoMP)
- LTE in unlicensed spectrum
- Machine Type communication (MTC)
- Network based Positioning
- Relay Nodes
- Smartphone Battery saving technique
- Support for Heterogeneous Networks (HetNet)
- Wi-Fi integration with LTE
- Enhanced inter-cell interference coordination (eICIC)
- Enhanced MIMO: up to 8x8 MIMO in downlink and on the UE side it allows 4X4 in uplink direction
- Enhanced Uplink multiple access: frequency-selective scheduling in uplink
- New enhanced PDCCH (ePDCCH)
- In Device Co Existence
- Minimization of drive test (MDT)
- Ran overload control for Machine type communication
- enhanced Small cells
- SON Improvements
- Worldwide roaming

LTE-A Pro specifications aim to address two primary goals for future LTE networks: boosting performance, and enabling Internet-of-things (IoT) connectivity. Some of the important enhancements are:

- Carrier Aggregation enhancements: up to 32 CC (component carriers)
- Enhancements for Machine-Type communication (eMTC)
- Elevation Beamforming / Full-Dimension MIMO/ high-order MIMO systems with up to 64 antenna ports at eNodeB
- Single-cell Point-to-Multipoint (SC-PTM)
- Narrowband IoT (NB-IoT)
- Enhanced multi-user transmission techniques: using superposition coding
- Enhancements for device-to-device communication.
- LTE in unlicensed spectrum enhancements
- Indoor Positioning

The RRM is an eNodeB application level function that ensures the efficient use of available radio resources by controlling and managing their assignment so that the Quality of Services (QoS) requirements of the individual radio bearers are met and the overall used radio resources on the system level are minimized. Indeed, it is the responsible for, among other functions, determining [8]:

- The type of the required resource control.
- The required resource sharing.
- The assignment methods.

In other words, the ultimate goal of RRM is to satisfy the service requirements at the smallest possible cost for the system. The RRM procedure can be divided into the following major entities [3]:

A. Radio bearer control (RBC): manages the establishment, the maintenance, and the release of radio bearers which involve the configuration of radio resources associated with them. , RBC takes into account:

- The over-all resource situation in LTE.
- The QoS requirements of in-progress sessions.
- The QoS requirement for the new service.

B. Radio admission control (RAC): In order to ensure high radio resource utilization and a proper QoS for in-progress sessions RAC admits or rejects establishment requests for new radio bearers thus it determines whether the bearer will be established at all, based on various admission control checks (availability of resources, licensing limits, etc.). Different realizations of LTE Radio Access Network (RANs) will run different admission control algorithms.

C. Dynamic packet assignment–scheduling: Dynamic Resource Allocation (DRA) or Packet Scheduling (PS) allocates and de-allocates resources including buffering and processing resources and resource blocks to user and control plane packets.

D. Link adaptation and power allocation: LA determines the MCS and the power allocation. The power control function set the transmit power levels such that the target SINR (at which the MCS is optimal) is reached.

E. Connection Mobility Control (CMC) & Handover control: it oversees the management of radio resources related to idle or connected mode mobility. And it maintain the radio link of a UE in active mode as the UE moves within the network from the coverage area of one cell to the coverage area of another

F. Inter-cell interference coordination: Inter-cell interference coordination has the task to manage radio resources (notably the radio resource blocks) so that inter-cell interference is kept under control.

G. Congestion control and Load balancing: handles uneven distribution of the traffic load over multiple inter-frequency and inter-RAT (radio access technology) cells, in order that radio resources remain highly utilized and the QoS of in-progress sessions is maintained to the largest possible extent while call-dropping probabilities are kept sufficiently small.

H. MIMO configuration control: it controls the configuration of antennas port

I. MBMS (multicast broadcast multimedia services) resource control: It control the transmission modes of multicast broadcast multimedia services (MBMS)

In this paper, the focus will be on resource scheduler and resource allocator, which we can model, by analogy to the model mentioned by the author of [9], as shown in Figure 1.

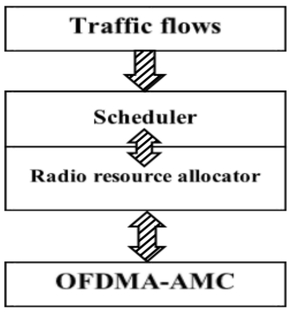

Figure 1. Radio resource scheduler/allocator

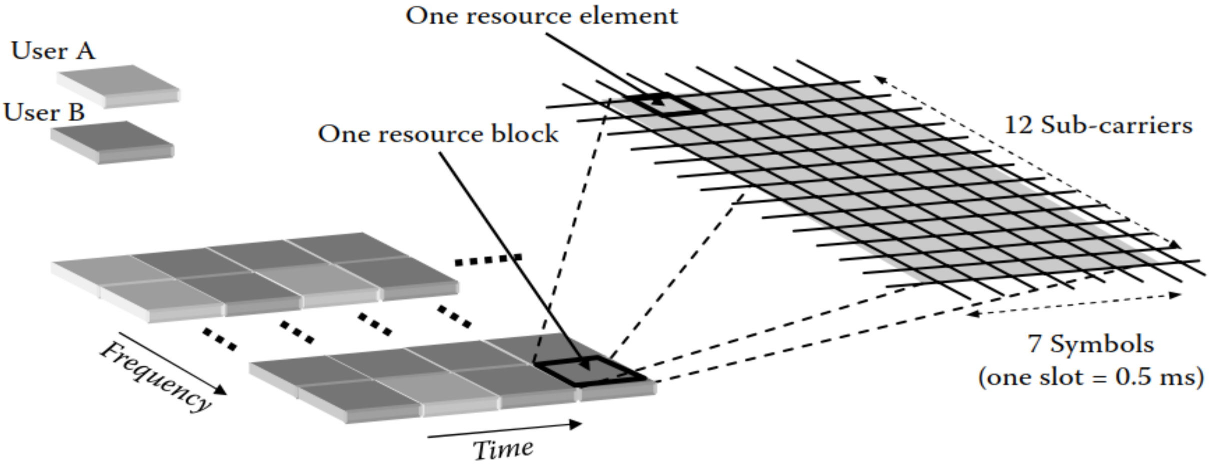

Figure 2. Uplink/downlink resource grid

Figure 2 shows the resource grid of the uplink and downlink shared channels. The smallest unit in the resource grid is the resource element (RE), which corresponds to one subcarrier during one symbol duration. These resource elements are organized into larger blocks in time and in frequency, called resource block (RB). RB is the smallest unit of resources that can be allocated to individual users to allow simultaneous communication with BS. It has dimensions of subcarriers by symbols: 12 sub-carriers (15 kHz) or 24 sub-carriers (7.5 kHz) in the frequency domain and 6 or 7 symbols in the time domain. The number of symbols depends on CP in use. The RB occupies exactly one slot of the duration of 0.5ms. Two slots form a subframe with a duration of 1 millisecond. A subframe represents the scheduling time of the LTE-A network wherein the 10 consecutive subframes constitutes one frame. The number of parallel RBs in each subframe depends on the system bandwidth. Two consecutive RBs are called Scheduling Block (SB) or transmission time interval (TTI), which is the smallest resource unit that the scheduler can process and it's also a scheduling period [10][11]. In addition, and with a collaboration with the Modulation and Coding Scheme (MCS), the number of RBs decides the transport block size (TBS) in each TTI [12].

In order that the eNB performs appropriately the scheduling, users should report at each TTI their instantaneous downlink channel conditions to the eNB. The scheduler determines which RBs from different flows will be processed in the next phase (as shown in Figure 3 and Figure 4) and their orders, based on channel conditions, buffers status, head of line (HOL) packet delays, and service types [13]. Then the allocator assign the RBs to users. An RB can be simultaneously assigned to more than one user in each scheduling interval.

Furthermore, LTE-A introduces three types of resource allocation for both downlink and uplink and each type uses a predefined procedures and specifies the way in which resource blocks are allocated for each transmission. However, no standards was defined for scheduling or for optimal resource allocation algorithm.

In the literature, there are many solutions for resource allocation and scheduling problem, I will only mention some of them:

The work of [14] suggests a dynamic resource allocation (DRA) to improve network capacity. According to user's link quality DRA is critical in OFDMA system.

The work of [15] proposes a two-layer scheduling architecture for LTE multimedia service.

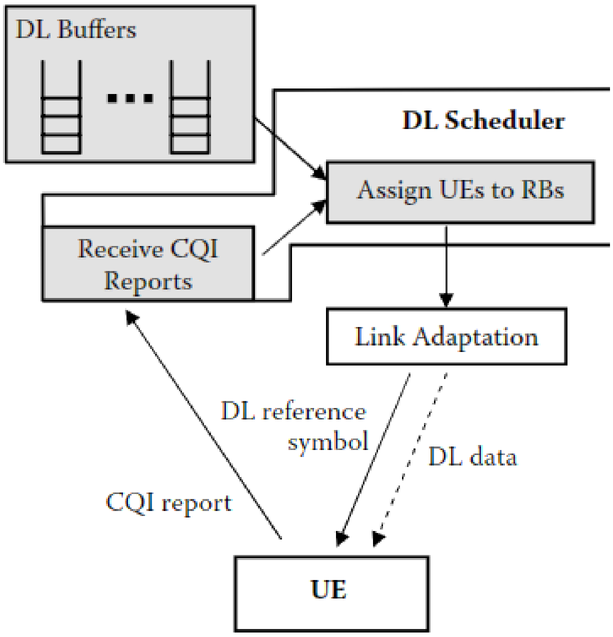

Figure 3. DL scheduler functions

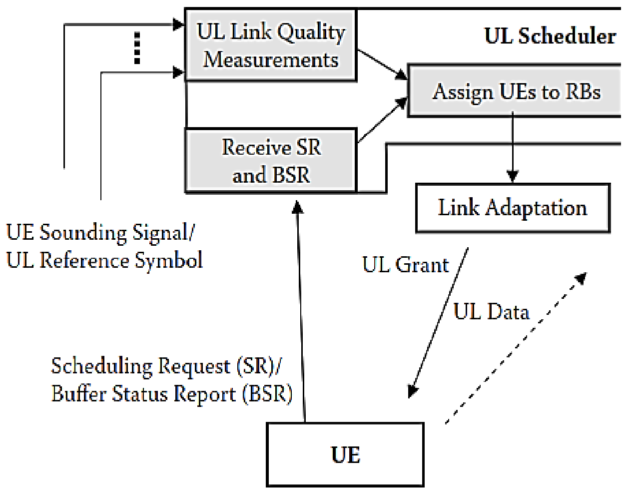

Figure 4. UL scheduler functions

The work of [16] studies the efficiency of the OFDMA downlink for different vehicular user densities by performing adaptive resource allocation for users whose instantaneous channel realizations are unavailable at the transmitter but known by the receiver. The work addresses also the problem of maximizing the sum-capacity of the system subject to user minimum Quality of Service (QoS) requirements. This approach lead to higher throughput gains in areas where a large number of vehicular users can be found.

The work of [17] applies a Gale–Shapley algorithm to find the optimal matching between RB and UE by considering channel conditions and the desired QoS.

The work of [18] suggests a novel uplink channel allocation scheme for real-time connections using the information of interference level and channel occupancy collected at cognitive femtocell access points and their covering macro base station (MBS). This flexible scheme provide lower unsuccessful probability of new connection requests compared to femtocell-access-point (FAP)-based and MBS-based uplink channel allocation schemes.

The work of [19] suggests a less complex centralized scheme for joint sub-carrier pairing and allocation along with relay selection and fairness constraint in multi-user relay networks.

The work of [20] proposes Virtual Cluster-based Proportional Fairness scheme that exploits the link adaptation information available at MAC layer to form virtual clusters. It ensures a minimum throughput for all users in the coverage area by assigning contiguous resource blocks, proportional to the throughput and the number of users in a particular cluster or group.

The work of [21] proposes a multi-objective resource allocation scheme to achieve simultaneously efficient resource utilization, fairness guarantee, interference mitigation and reduced complexity in a satisfactory manner. This scheme uses a weighted sum approach and an ant colony optimization algorithm.

The work of [22] proposes two resource allocation schemes, which are based on Particle Swarm Optimization (PSO) and hybrid PSO-GA (Genetic Algorithm) to maximize the system throughput.

The work of [23] gives a Self-Organized Dynamic Fractional Frequency Reuse Resource Allocation scheme (SODRA-FFR) which dynamically allocates frequency resources to cell inner and outer regions in relay based LTE-A networks to improve cell edge performance and maximize fairness among UEs.

The work of [24] proposes a buffer-aware adaptive resource allocation scheme for LTE downlink transmission to improve the overall system throughput while providing statistic QoS guarantee and keep certain fairness among users.

The work of [25] adopts the max-CQI method to compute RB allocation, and then asks non-urgent flows to return a fraction of their allocated RBs. Those RBs are redistributed among the flows being threatened by packet dropping.

3. An extensive review on Radio Resource Allocation Optimization in LTE (RRAOL) as a Field of Research

Radio resource allocation optimization is the most important subject in wireless networks [26]. Therefore, so many studies try to handle this problem. In fact, to start our study we should summaries all the previous studies and begin from where they stopped at. For this reason, table 1 will give some of the significant and recent concurrent surveys/reviews.To the best of our knowledge, no paper in the literature cover exactly our subjects meaning reviewing different contribution that studies the use of GT in radio resource allocation optimization in LTE Advanced.

By cons, many studies and researches used different optimization methods, such as mathematical programming (MP) and Global optimization (GO), etc. However, those methods can be a useful tool whenever the problems can be framed in terms of optimality locally or globally. In spite of the good results given by those methods, they show some difficulties and drawbacks, some of them are listed below [27-28]:

- The computational effort required which increases with the size of problem.
- Infinite running time of algorithms in high dimension problems and multimodal problems.
- Global optimality cannot be guaranteed by stochastic methods given that random elements are involved while deterministic methods algorithm took infinite running time to solve them.
- Non-convexity, non-smoothness and non-monotonicity functions.
- Noisy gradient: Many optimization methods rely on gradients of the objective function. If the gradient function is not given, they are computed numerically, which induces errors. In such situation, even if the objective function is not noisy, a gradient-based optimization may be a noisy optimization.
- Multi-extremal problems may have an exponential number of local minima.
- Problems with very little information available on their mathematical structure.

Therefore, and due to all previous drawbacks that other methods has showed in practice and that game theory can overcome, this paper will focus on the use of GT.

Furthermore, before optimizing a system, we build a model and we take into consideration the rules below [29]:

- Ease of understanding the model.
- Ease of detecting errors in the model.
- Stability of the model.
- Ease of computing the solution.

Figure 5 describes the general process used to optimize problems.

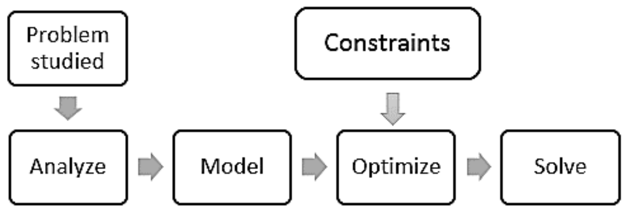

Figure 5. General optimization process

4. Game theory

GT is a discipline aimed at modelling situations in which decision makers have to make specific actions that have mutual possibly conflicting consequences [30-32]. It is a formal framework with a set of mathematical tools to study the complex interactions among interdependent rational players [33]. Started with Francis Waldegrave letter [34], as stated by Paul walker in [35] which presents a chronological outline of the history of GT, the main basis of GT history can be considered an outgrowth of the seminal works in [5],[30-33], [36-42].

GT is based on the concept of strategy (actions made by a player when challenged to solve a problem) and payoff (outcome of this strategy), it provides an appropriate solution if the following assumption are properly satisfied:

- A player can adopt multiple strategies for solving a problem.
- There is an availability of predefined outcomes.
- The overall outcome for all players would be zero at the end of game.
- All players in the game are aware of the game rules as well as outcomes of other players.
- Players take a rational decision to increase their own profit.

Besides, it has tree representations form:

- The extensive form (game tree) is a graphical representation of a sequential game [43]. It provides information about the players, payoffs, strategies, and the order of moves. It consists of vertices, which are points at which players can take actions, connected by edges, which represent the actions that may be taken at that node [44].
- The normal form (strategic), as introduced in [31] and in [5], is a matrix representation of a simultaneous game. Each rows or column represents a strategy and each box represents the payoffs to each player for every combination of strategies. Generally, such games are solved using the concept of a Nash equilibrium [45].
- Characteristic function form (coalitional) was introduced in [5], it concentrates on coalition formation and the distribution of pays. In fact, it allows us to consider games in which the players can collaborate with each other to form coalitions, or groups of players, that can achieve more than a single player could individually. It is a critical model to describe what occurs in the real world [46].

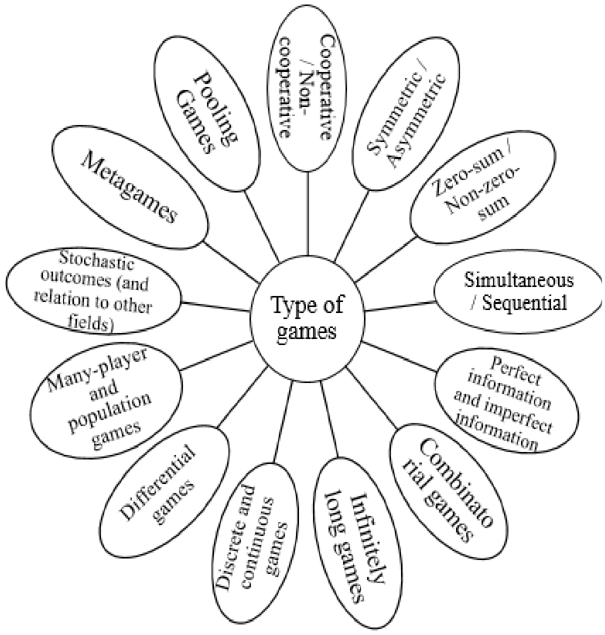

Figure 6. Different types of game

Furthermore, GT has several categories, as shown in Figure 6; each one of them has its specific features and fits a specific type of problems. Thereby, we should choose the right type of game before starting to solve the problem.

In section IV, we will give some examples where only some of the previous GT-categories are used and other notions related to the subject, for this reasons it is necessary to give the next key terms and definitions:

- Cooperative game: it is a game often defined in term of characteristic function form, where coalitions (collective decision-maker) of players may impose a cooperative behaviour and choose which coalitions to form, according to their estimate of the way the payment will be divided among coalition members. It's, indeed, a competition between coalitions of players rather than between individual players.
- Non-cooperative game: players here make decisions independently and are not able to be committed to each other's unlike in cooperative games.
- Bargaining game: or Nash bargaining game (NBS) it is a game in which two or more players bargain over how to gains from trade. In fact, if the total request is greater than the available neither of them gets its gain. Nash bargaining solution is a Pareto optimality to NBS.
- Strategy: a set of moves or actions a player will follow in a given game, it determines that player will take at any stage of the game. In addition to that, the outcome depends on the action of other players too.
- Utility function: is a mathematical way to represent a player preference or satisfaction.
- Nash equilibrium (NE): is a fundamental solution-concept in the GT. In fact, a NE is an actions profile, which satisfies that no player can unilaterally improve its own utility. Or we can put it like this, at NE no player has any incentive to change its strategy. Accordingly, NE is a stable outcome of the game.

Theorem 1[47]: The function must be quasi-concave (or quasi-convex) if it is concave (or convex).

Theorem 2[47]: lets denote a game by $\mathcal{g} = [\mathrm{N}, \{\mathrm{P_i}\}, \{\mathrm{u_i}(\cdot)\}]$ where N is the number of players and $\{\mathrm{P_i}\}$ is the action set for the players and $\{\mathrm{u_i}(\cdot)\}$ is the utility functions set for the players. There is a Nash equilibrium at least in a game $\mathcal{g}$ if:

1) $\mathrm{P_i}$ are subsets of $\Re$n and are nonempty, compact, and convex;

2) $\mathrm{u_i}$ are continuous in $\mathrm{P_i}$,

3) $\mathrm{u_i}$ are quasi-concave in $\mathrm{P_i}$.

Accordingly, we can easily prove the existence of NE.

5. Game theory in LTE-A resource allocation

5.1. A Review of GT on RRAOL as a Field of Research

As we mentioned before, GT has taken a lot of focus in last years, therefore, this paper will focus on the use of GT in LTE/LTE-A resource management. Indeed, in [48] authors demonstrate how GT can be applied to wireless network. Following a layered perspective, it has been explained how to capture wireless networking problems in game-theoretic formulations, emphasizing on which game type best suits each application field and on how the corresponding utility function may be constructed. More importantly, it presents a mapping between the basic components of a game and the entities of wireless networks that should be designated before applying the theory to a wireless-specific problem, as follows:

- Game component: Entities, processes or elements of wireless networks.
- Players: Network nodes, service providers or customers.
- Resources: All kinds of resources needed by nodes to communicate successfully (spectrum, power, bandwidth, etc.).

- Payoffs: Estimated by utility functions, based on QoS merits (delay, throughput, SNR, etc.)

Table 1 gives some examples from the literature of the application of game theory in resource allocation and scheduling. Nearly, all researches exploit cooperative or non-cooperative games and the Nash equilibrium concept.
In addition, almost all works simplify the problem by taking only: a single cell, a direction (uplink/downlink), a finite number of users, a network without interferences, some ideal assumption like equal transmit power…
The major focus of the works in the literature seems to be the allocation of power/subcarrier and the optimisation of sum network/user rate and QoS, only some works takes into accounts other component like energy, frequency level, etc

YEAR	Reference	TITLE	The goal of the paper	Limitation
2009	[49]	An Overview of Downlink Radio Resource Management for UTRAN Long-Term Evolution	This paper reviewed the basic LTE framework for the primary base station downlink RRM mechanisms for the shared unicast channel	It does not include GT. It only focuses on one direction of the LTE, the downlink. It doesn't cover the LTE Advanced
2013	[50]	A review of resource allocation techniques for throughput maximization in downlink LTE	This paper reviewed several resource allocation schemes for throughput maximization in LTE downlink.	
2014	[51]	A review of performance analysis of a downlink LTE system using different radio resource allocation schemes (RRAS)	This paper reviewed several resource allocation schemes for performance analysis in downlink direction for LTE systems.	
	[52]	A Survey on LTE Downlink Packet Scheduling	This paper reviewed the different proposed scheduling algorithms under variable conditions	
	[53]	A Survey of Radio Resource Management for Spectrum Aggregation in LTE-Advanced	This paper reviewed On-going research on the different RRM aspects and algorithms to support carrier Aggregation in LTE-Advanced	It does not include GT. It only focus on Spectrum Aggregation in LTE-Advanced
	[54]	A survey on resource allocation techniques in OFDM(A) networks	This paper reviewed the radio resource allocation techniques in Orthogonal Frequency Division Multiplexing (OFDM) and Orthogonal Frequency Division Multiple Access (OFDMA) systems	It studies all various schemes in the OFDM and OFDMA networks generally. No focuses on game theory methods
2013	[55]	A Survey on Dynamic Spectrum Access Techniques in Cognitive Radio Networks	This paper reviewed various techniques of dynamic spectrum access in cognitive radio (CR) networks, namely, auctions, game theory, Markov models and multi-agent systems.	It particularly studies all various techniques of dynamic spectrum access in CR. However, it does not focus on game theory methods and it does include all resource allocation scheme in LTE network.
2015	[56]	Resource Allocation in LTE: An Extensive Review on Methods, Challenges and Future Scope	This paper reviewed the basic of resource allocation and different scheme and algorithm used in the literature to solve this problem in LTE	It studies all various schemes in Resource Allocation in LTE network generally. However, It does not focus on game theory methods particularly.

Table 1: List of surveys and reviews of resource allocation in LTE/LTE-A

Year	Reference	Title	Method and game type	Levels of optimization	Conclusion
2008	[57]	Adaptive resource allocation for downlink OFDMA Networks using cooperative Game theory	Cooperative game, waterfilling game, Nash bargaining equilibrium	Power, subcarrier	This work proposes an adaptive resource allocation for downlink OFDMA single cell using a cooperative game and exploiting the waterfilling and NB concepts. The work finds a good trade-off between the overall rate and fairness comparing to the maximizing system capacity and the max-min fairness algorithm and it ensures the user's QoS demand
2009	[58]	A Game Theoretical Formulation for Proportional Fairness in LTE Uplink scheduling	Cooperative game bargaining game, heuristic algorithm	Subcarrier, scheduling	This work studies the uplink scheduling in LTE systems considering Localized FDMA (a type of subcarrier mapping). It presents a game theoretical formulation that links proportional fairness to the logarithm of the throughput as a utility function to be maximized. This framework can be applied in both centralized and distributed scenarios. Finally, a heuristic scheduling algorithm achieving this proportional fairness with low complexity is then designed and tested.
2009	[59]	Distributed Resource Allocation Based on Game Theory in Multi-cell OFDMA Systems	Non-cooperative game, potential game	Power, subcarrier	This work develops a framework for distributed resource allocation in multi-cell OFDMA systems, based on non-cooperative potential game that integrates a mechanism of shutting down inefficient users in order achieve higher system energy efficiency
2009	[60]	K -Player Bayesian Waterfilling Game for Fading Multiple Access Channels	Bayesian game, Waterfilling Game	Power, Rate	This work studies a distributed resource allocation problem of K -user fading multiple access channels (MAC) where users are rational, selfish, and each one carries the objective of maximizing its own achievable data rate. in addition, they have local information about the channel state information (CSI)
2009	[61]	Performance of Decentralized Interference Coordination in the LTE Uplink	Non-cooperative game	PRB, spectrum, interference	This work proposes a non-cooperative game approach to solve the PRB allocation problem in order to coordinate interferences among cells.
2010	[62]	A Bayesian Game-Theoretic Approach for Distributed Resource Allocation in Fading Multiple Access Channels	Bayesian Game	Power, sum rate	This work studies a distributed resource allocation problem in K -user fading multiple access channels where user have complete information only about their own channel gains and they are assumed to selfishly maximize their average achievable rates. Therefore, the algorithm optimize the network sum-rate maximization.
2010	[63]	A Characterization of Resource Allocation in LTE Systems Aimed at Game Theoretical Approaches	Static game	Spectrum, scheduling	The paper presents a cross-layer approach, where scheduler and radio resource allocator exchange a limited amount of information to achieve a trade-off between sum-rate throughput and fairness among the users
2010	[64]	A game-theoretic approach to load balancing in cellular radio networks	Non-cooperative game, Nash equilibrium, linear pricing	Load Balancing	This work studies the load-balancing problem using a non-cooperative game and Nash equilibrium concept in order to increase user satisfaction level and the QoS in the overloaded cell.
2010	[65]	A Resource Allocation Using Game Theory Adopting AMC Scheme in Multi-cell OFDMA System	Non-cooperative game, Nash bargaining game	Power, Channel, capacity, interference	This work proposes a downlink resource allocation algorithm in multi-cell OFDMA system adopting AMC scheme to maximize the system capacity and to reduce the co-channel interferences.

2010	[66]	The Waterfilling Game-Theoretical Framework for Distributed Wireless Network Information Flow	Non-cooperative game, potential game, Water-filling Game.	Power, sum-rate	This work studies the power allocation in the downlink of distributed wireless small-cell networks, where multiple access points (APs) or small base stations send independent coded network information to multiple mobile terminals (MTs) through orthogonal channels
2011	[67]	A Delay-scheduler Coupled Game Theoretic Resource Allocation Scheme for LTE Networks	Cooperative game, bargaining game	Bandwidth, scheduling	This work Gives a two-level scheduler with game theoretic application that distributes resources among classes with fairness and then implements a delay-based scheduler to satisfy the strict levels of delay budget requirements of LTE classes.
2011	[68]	A Distributed Algorithm for Wireless Resource Allocation Using Coalitions and the Nash Bargaining Solution	Cooperative game, Nash Bargaining solution	Subcarrier	This work proposes a simple, low-complexity, fast and efficient distributed algorithm for subcarrier allocation in an LTE wireless channel based on coalition and Nash bargaining solution in order to reduce time requirement. However, the proposed algorithm demand a fairly limited signalling between the wireless users which imply that user might have to wait longer for access to the channel’s resources.
2011	[69]	A Fast and Fair Algorithm for Distributed Subcarrier Allocation Using Coalitions and the Nash Bargaining Solution	Cooperative game, Nash bargaining game	Subcarrier	This work proposes a low complexity, fast and fair distributed subcarrier allocation algorithm. Compared to the PF scheduler, this algorithm achieves almost an equivalent sum rate, a same fairness providing a fair operating point for all users. The algorithm minimizes execution time and overheads, therefore it’s suitable for implementation in real-time systems
2011	[70]	A Hybrid Approach for Radio Resource Management in Heterogeneous Cognitive Networks	Non-cooperative game, Stackelberg game, a Bayesian game	Spectrum	This work proposes a hybrid approach for radio resource management in heterogeneous cognitive networks in the presence of mobility combining distributed algorithm, non-cooperative game, Stacklberg and Bayesian game concepts. It studies the association problem in the context of distributed decision making in order to alleviate the burden from the base stations. The work proposes association methods that combine benefits from both decentralized and centralized design.
2011	[71]	A novel bargaining based power allocation for Coordinated Multiple Point transmission/reception	Bargaining game, patience factor, Rubinstein-Stahl	Power	This work proposes a distributed Rubinstein-Stahl Bargaining based Power Allocation (DBPA) scheme to explore the benefit of Coordinated Multiple Point transmission/reception (CoMP) by releasing the burden of X2 interface and reducing the exchange overhead between the cells using the Patience Factor (PF) concepts.
2011	[72]	A Novel Resource Allocation Algorithm in Uplink Multi-cell OFDMA Networks Based on Game Theory	Non-cooperative game	Power, subcarrier	This work presents a novel resource allocation algorithm based on game theory where subcarriers are allocated according to the normalized channel gain and power is allocation adopts a novel non-cooperative game model based on arc tangent function. To ensure fairness, we introduce a pricing function to the utility function.
2011	[73]	A game theoretic scenario for LTE load balancing	Cooperative game, non-cooperative game	Load Balancing	This work presents an efficient load-balancing algorithm for the LTE communication system combining two types of games namely cooperative and non-cooperative game in order to reduce congestion and to improve cell capacity. The algorithm show a significant reduction in dropped calls’ rate. In addition, it maintains a database of the neighbouring cells’ loads in each eNB to avoid unnecessary signalling between base stations.

2011	[74]	Adaptive Resource Allocation in Jamming Teams Using Game Theory	Non-cooperative game, pursuit-evasion game, zero-sum game, a continuous kernel game, a static game	Power, AMC	This work combines different games in order to optimize the power allocation and the adaptive modulation and coding (AMC) schemes in teams of decision makers. However, those teams consist of only 2 agents.
2011	[75]	Cognitive Base Stations in LTE/3GPP Femtocells: A Correlated Equilibrium Game-Theoretic Approach	Non-cooperative game, Static game, distributed algorithm.	PRB, Spectrum	This work considers downlink spectrum allocation in an OFDMA-Based Microcellular-femtocell LTE. It formulates the competition amongst cognitive HeNBs for spectrum resources as a non-cooperative game-theoretic learning problem where each HeNB seeks to adapt its strategy in real time. It formulates the resource block (RB) allocation among HeNBs using a static game framework, using the correlated equilibrium solutions concept. It finally proposes a distributed RB access algorithm to compute the correlated equilibrium RB allocation policy.
2011	[76]	Efficient Distributed Dynamic Resource Allocation for LTE Systems	Cooperative game, Nash bargaining game	PRB, interference	This work proposes an efficient distributed dynamic resource allocation (DDRA) scheme to coordinate the inter-cell interference and verify the existence of the Nash equilibrium. It formulates the ICIC as a non-cooperative game. This scheme can be implemented in sequential or parallel manner in the LTE uplink and downlink scenarios to mitigate the inter-cell interference effectively.
2011	[77]	LTE network planning based on game theory	Cooperative game, Nash equilibrium	Power, BS position planning	This work studies LTE network planning (BS position planning and BS power allocation). It uses the distribution power allocation algorithm to guarantee the edge user’s maximum data transfer rate during determination BS power. For the BS power allocation, it applies cooperation game theory. The initial conditions are calculated by the traffic search method and update during the game theory working.
2011	[78]	Resource allocation based on integer programming and game theory in uplink multi-cell cooperative OFDMA systems	Non-cooperative game, cooperative game, integer programming	Subcarrier	This work proposes a semi-distributed resource allocation framework for the resource optimization in multi-cell uplink cooperative OFDM systems combining three methods cooperative game, non-cooperative game and the integer programming to enhance the system sum rates , to regulate power allocation in the two time slots and to achieve the fairness among users.
2011	[79]	Resource Allocation Using Shapley Value in LTE Networks	Cooperative game, Bankruptcy game, Shapley value, EXP-RULE scheduling algorithm	Bandwidth, scheduling	This work transforms the LTE downlink-scheduling problem into a bankruptcy game problem. Then, it applies the Shapley value to provide fair resource allocation among flows. It finally improves the performance of resource allocation in LTE for downlink system. however, It studies only one single cell
2011	[80]	Stackelberg Games for Energy-Efficient Power Control in Wireless Networks	Stackelberg Game	Power, Energy	This work deals with the energy-efficient power control problems in a cognitive wireless networks where some users are equipped with cognitive sensors while others are not. They choose their control policy freely and selfishly in order to maximize their individual energy efficiency.
2011	[81]	User Satisfaction Based Resource Allocation in Future Heterogeneous	Auction game, equilibrium solution	Bandwidth	This work studies a user-centric quality of experience based resource allocation problem where operators compete for users request using auction approach. It also studies user satisfaction for several types of users and different class of services. It proposes a framework for short-term user-operator contractual vision.

		Wireless Networks			Finally, it studies the equilibrium solution for the mentioned problem using a game-theoretic approach.
2012	[82]	A Game Theoretic Approach to Spectrum Management in Cognitive Radio Network	Bertrand game, Stackelberg game, Nash equilibrium	Spectrum	This work proposes CR network models for providing spectrum management, which includes spectrum trading, and spectrum competition. The model includes multiple levels of QoS for different secondary users and takes into account the changes in the price. The work adopts a Bertrand game for the spectrum competition issue and a Stackelberg game for spectrum trading, using the Nash equilibrium solution for both games
2012	[83]	A new PRB sharing scheme in dual-hop LTE-advanced system using game theory	Repeated game, cooperative game	Spectrum, interference	This work proposes a dynamic Physical Resource Blocks (PRBs) allocation scheme in a dual-hop LTE-advanced by using game theory, to improve the radio capacity. It introduces a new repeated game, in which a selfish node can achieve cooperative spectrum opportunities sharing under the threat of punishment, in order to enhance the PRBs assignment to both nodes in the network while reducing the mutual interference between them. As result, the spectrum utilization is improved and the total achieved throughput is enhanced in the network.
2012	[84]	A Quality-of-Experience driven bidding game for uplink video transmission in next generation mobile networks	Auction game	PRB	This work considers the centralized problem of uplink resource allocation for real-time multimedia communications which requires the availability of meta information about the multimedia content and channel information of all users. The work proposes a Quality of Experience (QoE) driven bidding game for decentralized uplink resource allocation among multiple mobile video producers. In addition, it defines the price per resource unit on a Mean Opinion Score (MOS) scale.
2012	[85]	A real-time services performance and interference mitigation for femtocell scenarios in LTE networks	Cooperative game, bargaining game, shapely value, bankruptcy game	Bandwidth, interference	This work proposes an enhancement of the well-known four-colouring method for femtocell interference mitigation by combining it with cooperative bargaining game theory. It examines the behaviour of real-time services over a femtocell scenario bearing in mind important QoS constraint.
2012	[4]	A Utility Based Resource Allocation Scheme with Delay scheduler for LTE Service-Class Support	Cooperative game	Bandwidth, PRB, scheduling	This work proposes a two-level scheduler with a sigmoid utility based cooperative game theoretic application in the first level that distributes physical resource blocks among classes with different QoS requirements and a delay based air interface scheduling algorithm in the second level that satisfies the strict levels of delay budget requirements defined for LTE classes. Lagrangian formulation is used to find the associated Pareto Optimality.
2012	[86]	A Game theoretical approach for spectrum sharing in cognitive radio systems with payoff perturbations	Non-cooperative game, equilibrium selection, payoff dominance, the focal-point effect, Nash equilibrium	Spectrum	This work studies a spectrum allocation game where K cognitive radio systems compete for a number of free resource blocks in frequency domain. It focuses on the impact of the perturbations in the payoff functions and the problem of equilibrium selection. Finally, it demonstrates the performance of the spectrum allocation game in an LTE system context
2012	[87]	Bargaining Solutions for Multicast Subgroup Formation in LTE	Nash bargaining game	PRB	This work compares four different bargaining games and then it proposes an effective framework using cooperative bargaining game to find alternative solutions to the Conventional Multicast Scheme (CMS).

2012	[88]	Energy efficiency games for backhaul traffic in wireless networks	Non-cooperative game, potential game, Gradient method, Multi-objective optimisation,	Power, Energy, load balance	This paper proposes a game-theoretic framework for improving energy efficiency of wireless networks by focusing on energy aware resource allocation in backhaul cloud computing. Then it formulates the system power consumption and load balance as a multi-objective optimisation and finally, it adopts a non-cooperative game, which is proved as a potential game.
2012	[89]	Energy efficient coordinated radio resource management: A two player sequential game modelling for the long-term evolution downlink	Sequential Game, Simultaneous game	PRB, Inter-cell interference	This work presents a Sequential Game Coordinated Radio Resource Management (SGC/RRM) algorithm to dynamically mitigate the effects of ICI. The game players (eNBs) communicate their instantaneous offered load information, via the X2 interface, and decide what transmission frequency band restrictions to adopt in order to mitigate ICI.
2012	[90]	Energy-efficient power allocation with dual-utility in two-tier OFDMA femtocell networks	Non-cooperative, strategic game, dual-utility game	Power	This paper proposes an energy-efficient power allocation scheme in two-tier OFDMA femtocell networks utilizing a non-cooperative game with dual-utility, where each MBS maximizes the energy efficiency considering both circuit and transmission power, and each FBS improves its SINR utility. The proposed power game is decomposed in L parallel sub-games, which has the same equilibrium set with the proposed scheme.
2012	[91]	Game Theoretic subcarrier and power allocation for wireless OFDMA networks	Cooperative game, Bargaining game	Subcarrier, power	The objectives of this work is to maximize the aggregate payoffs for the users, and the overall system rate for single-cell downlink OFDMA systems
2012	[92]	Interference coordination in CoMP with transmission scheduling and game theoretical power reallocation	Non-cooperative game, Water-Filling game	Power, scheduling, interference	This work proposes a framework to maximize the total edge user throughput in CoMP (Cooperative Multi-Point) based LTE-A networks. It includes a simple transmission scheduling algorithm based on RSRP (reference signal receiving power) and a non-cooperative game for power reallocation to reduce the co-channel interference.
2012	[93]	Interference mitigation by dynamic self-power control in femtocell scenarios in LTE networks	Cooperative game, Bargaining game	Power, interference	This work proposes a method that carries on an efficient scheme in order to mitigate interference in femtocell scenarios by using a dynamic self-power transmission control based on bargaining cooperative game. The proposed solution uses the modulation and coding scheme (MCS) to obtain the optimum power value/sub-bands, which assures a trade-off between SINR and bit-rate efficiency.
2012	[94]	Optimal resource allocation in femtocell networks based on Markov modelling of interferers' activity	Non-cooperative game, Bayesian GAME, Markov modelling	Power, bit, interference	This work proposes an optimal power/bit allocation strategies to overcome interference management problem based on the estimation of the interference activity statistical parameters
2012	[95]	Potential Games for Energy-Efficient Power Control and Subcarrier Allocation in Uplink Multi-cell OFDMA Systems	Potential game, non-cooperative game, Nash equilibrium, social optimum	Power, Energy, subcarrier, SINRs	This work considers the problem of non-cooperative resource allocation in the uplink of OFDMA multi-cell networks. It adopts a potential game framework to obtain a non-cooperative game convergence to a NE. However, it has not been possible to show uniqueness of the NE for the considered games

2012	[96]	Power-Efficient Radio Resource Allocation for Low-Medium-Altitude Aerial Platform Based TD-LTE Networks	Cooperative game	PRB, power	This work proposes a power-efficient radio resource allocation mechanism for both the Aerial LTE downlink and uplink, which is modelled as a cooperative game. It imposes an attractive trade-off between the achievable throughput and the power consumption while ensuring fairness among users.
2012	[97]	Radio Resource Allocation for Low-Medium-Altitude Aerial Platform Based TD-LTE Networks against Disaster	Cooperative game	PRB, power	This work proposes a radio resource allocation for Low-Medium-Altitude Aerial Platform based time-division-duplex LTE for both directions (i.e. the uplink and the downlink), which is modelled as a cooperative game to provide real-time voice communications with as many users as possible (capacity).
2012	[98]	Resource Allocation for Real Time Services Using Cooperative Game Theory and a Virtual Token Mechanism in LTE Networks	Cooperative game, bankruptcy game, Shapley value, virtual token mechanism, EXP-RULE algorithm	Bandwidth	This work proposes a two level resource allocation scheme to distribute bandwidth fairly and to improve the QoS for Real-time multimedia services in LTE downlink system combining cooperative game theory, virtual token mechanism, and the EXP-RULE algorithm. This proposed scheme allows a low complexity implementation,
2012	[99]	Resource allocation scheme for orthogonal frequency division multiple access networks based on cooperative game theory	Cooperative game, non-transferable utility (NTU) game, (TU) game, bankruptcy game, Nash bargaining game	Power, rate, subcarrier	This work uses two types of cooperative game, the non-transferable utility and transferable utility game, the Bankruptcy game and Nash bargaining game to dynamically allocates subcarrier, power and rate providing an acceptable trade-off between optimality in terms of overall system throughput and fairness.
2012	[100]	Self-Optimization of Downlink Transmission Power in 3GPP LTE-A Heterogeneous Network	Non-cooperative game, fuzzy logic inference	Power, interference	This work proposes a self-optimized downlink power allocation algorithm to efficiently use the transmission power while minimizing the interference to other users. It combines the game theory and fuzzy logic inference methods, which minimizes the required information exchange among eNBs and fulfils the requirement of self-optimization in SON concept.
2013	[101]	A Bankruptcy Game-Based Resource Allocation Approach among Virtual Mobile Operators	Bankruptcy game	PRB	This work proposes a bankruptcy game based dynamic wireless resource allocation approach among multiple virtual mobile operators VMOs. The satisfaction of payoffs each VMO is paid is evaluated with expectation index (EI).
2013	[102]	A Radio Resource Management Framework for Multi-User Multi-Cell OFDMA Networks Based on Game Theory	Non-cooperative game, auction game, Margin adaptive	Power, subcarrier, bit loading	This work suggests a radio resource management framework employing game theoretic concepts for Multi-User Multi-Cell OFDMA Networks to minimize their required transmit power. However, the distributed nature of the algorithm results in lower total offered bit rate.

2013	[103]	A Game-Theoretic Approach for Energy-Efficient Contention-Based Synchronization in OFDMA Systems	Non-cooperative game, Nash equilibrium, best-response dynamics.	Power, Energy, Detection strategy	This work provide an energy-efficient perspective to the problem of contention-based synchronization in OFDMA communication systems using non-cooperative game model. In the proposed game, each one trades off its available resources (transmit power and detection strategy) so as to selfishly maximize its own revenue while saving as much energy as possible and satisfying quality-of-service. finally , it applies an iterative algorithm based on best-response dynamics to let each user achieve the equilibrium point in a distributed manner.
2013	[104]	ABSF offsetting and optimal resource partitioning for eICIC in LTE-Advanced: Proposal and analysis using a Nash bargaining approach.	Cooperative game, Nash bargaining game	Rate	This work proposes an ABSF offsetting approach based Nash cooperative bargaining game. The proposed algorithm aims to reduce the blanking rate at the femtocell (aggressor) while preserving the required optimal blanking rate at the macro-cell. It also studies the problem of optimal resource partitioning and offset assignment in the ABSF mode.
2013	[105]	Backhaul-constrained optimization for hybrid access small cells.	Stackelberg game	Power, Capacity, user admission, interference	This work proposes a Stackelberg game to model the interactions between MNO and Small cell holders' (SHs') combining refunding with technical specifications, including SINR, interference temperature, and the limited-capacity backhaul. Then, it suggests a low complexity two-phase guest user admission and power allocation algorithm.
2013	[106]	Collaborative Sub-Channel Allocation in Cognitive LTE Femto-Cells: A Cooperative Game-Theoretic Approach	Cooperative game, Nash equilibrium	Sub-Channel	This work proposes a cooperative game framework for the downlink sub-channel allocation problem to maximize the overall network utility and it interprets the modified core as the equilibrium notion. It proposes a distributed coalition formation algorithm whereby users myopically maximize their expected payoff by choosing the (f)BS to join. If each user follows this algorithm, the entire LTE network eventually reaches the maximum feasible total throughput, which corresponds to the core of the defined coalition formation game.
2013	[107]	Distributed downlink resource allocation in cellular networks through spatial adaptive play.	Potential game	Power, Channel, Subcarrier, BS association	This work proposes a potential game framework for distributed resource allocation in downlink of mobile cellular networks to perform power allocation, subcarrier selection and base station association simultaneously.
2013	[108]	Distributed resource allocation for device-to-device communications underlaying cellular networks.	Cooperative game, transferable utility	PRB, Spectrum	This work proposes a distributed and cooperative game with transferable utility to optimize the system performance in device-to-device (D2D) communications underlying cellular networks.
2013	[109]	Dynamic rate allocation in Markovian quasi-static multiple access channels: A game theoretic approach	Cooperative Game, NTU game , run long game, Static game	Rate	This work studies the multiple access channels whose channel coefficients follow a quasi-static Markov process on a finite set of states. It utilizes the game theoretical concepts of time consistent Core and Cooperation Maintenance to address the issue of allocating transmission rates to users.

2013	[110]	Dynamic spectrum scheduling for carrier aggregation: A game theoretic approach	Distributed algorithm, cooperative game, Bayesian game, Bayesian Nash equilibrium, Nash bargaining equilibrium	Spectrum, scheduling	This work proposes a Dynamic Internetworking Carrier Aggregation (DI-CA) framework, combing multiple concepts namely, a distributed coalition formation, a distributed Bayesian coalition formation, Bayesian Nash equilibrium, Nash bargaining solution, to optimize spectrum scheduling among different operator
2013	[111]	Efficiency resource allocation for device-to-device underlay communication systems: a reverse iterative combinatorial auction based approach.	Auction Game, Reverse Iterative Combinatorial	Power, Channel, Spectrum	This work proposes an innovative resource allocation scheme to improve the performance of mobile peer-to-peer, i.e., D2D, communications as an underlay in the downlink (DL) cellular networks. To optimize the system sum rate over the resource sharing of both D2D and cellular modes, we introduce a reverse iterative combinatorial auction as the allocation mechanism.
2013	[112]	Energy-aware cooperative content distribution over wireless networks: Optimized and distributed approaches.	Cooperative game	Energy, rate	This work proposes a cooperative game framework to address the problem of optimal energy-aware content distribution over wireless networks with mobile-to-mobile cooperation.
2013	[113]	Energy-aware resource allocation for device-to-device underlay communication.	Non-cooperative game, Auction game	Power, channel, energy, price	This work proposes a non-cooperative resource allocation scheme to improve the performance of D2D communication in which D2D UEs are viewed as players competing for channel resources and adjusting the transmit power on each channel and optimizing the power and energy consumption. Then, it proposes an efficient price-auction game.
2013	[114]	Evolutionary Dynamics of Resource Allocation in the Colonel Blotto Game	Evolutionary game, the Colonel Blotto game	PRB	The objectives of this work is the maximization of payoffs via the Colonel Blotto game considers the competition of two players with different total resources to be distributed among a set of items
2013	[115]	Fairness resource allocation in blind wireless multimedia communications.	Auction game, convex optimization	PRB	This work proposes an α-fairness resource allocation scheme for blind multimedia communications using auction game.
2013	[116]	Game theoretic distributed dynamic resource allocation with interference avoidance in cognitive femtocell networks.	Non-cooperative game, zero-sum game, water-filling game	Power, spectrum, interference	This paper proposes a decentralized dynamic resource allocation scheme using game theoretic regret matching procedure to enhance the spectrum efficiency for cognitive femtocell networks. The proposed scheme can avoid interference to macro cell and the other femtocell user equipment's.
2013	[117]	Joint Optimization of Collaborative Sensing and Radio Resource Allocation in Small-Cell Networks	Non cooperative game, cooperative game, strategic game, water-filling game	Power, rate, spectrum, interference	This work proposes a joint optimization of sensing parameters and RRA in order to maximize the opportunistic throughput, under the constraint of limiting undue interference towards primary users.
2013	[118]	Joint scheduling and resource al-	Stackelberg game	Power, channel, interference	This work proposes a joint scheduling and allocation of channel resources and power scheme to improve the performance of D2D communication using a

		location for device-to-device underlay communication			Stackelberg game framework. It takes network throughput and UEs' fairness into account by performing interference management.
2013	[119]	Multicast service delivery solutions in LTE-Advanced systems.	Cooperative game, Bargaining game	PRB, bandwidth	This work proposes a cooperative bargaining game to model the RRM policies for the efficient delivery of multicast services in multicarrier LTE-Advanced systems and shows how the relation between fairness and system efficiency can be controlled.
2013	[120]	On the compound impact of opportunistic scheduling and D2D communications in cellular networks.	Cooperative game	Power, MCS, user, scheduling	This work proposes a simple, scalable and energy-efficient D2D-assisted opportunistic strategies. It uses a cooperative game theory approach to analyse the cluster formation mechanism in realistic network scenarios, in which throughput and fairness are boosted via user cooperation. It shows that proportional fair-based intra-cluster payoff distribution brings significant incentive to all mobile users regardless of their channel quality.
2013	[121]	Pareto-optimal Nash equilibrium in capacity allocation game for self-managed networks.	Distributed non-cooperative game	Capacity, rate	This work proposes a distributed non-cooperative game perspective to model the capacity allocation and deal with the problem of maximizing network utility. An efficient-decentralized algorithm is given in order to strongly compute the Pareto-optimal strategies, and to constitute a pure Nash equilibrium. Finally, the properties of the introduced game related to the Price of Anarchy and Price of Stability are discussed.
2013	[122]	Refunding for small cell networks with limited-capacity backhaul.	Non-cooperative game, stackelberg game	Power, capacity	This work proposes a non-cooperative stackelberg game to analyze the interactions between the MNO and SHs, with MNO being a leader and SHs being followers. It proposes also a look-up table approach at MNO and an optimal power allocation algorithm at SHs through majorization theory to reach a perfect equilibrium.
2013	[123]	Resource allocation for device-to-device communications underlaying LTE-advanced networks.	Non-cooperative game, column generation method	Power, PRB, Spectrum, scheduling, interference	This work proposes a resource allocation scheme for D2D communications based on a column generation method and non-cooperative game. The objective is to maximize the spectrum utilization by finding the minimum transmission length in terms of time slots for D2D links while protecting the cellular users from harmful interference and guaranteeing the QoS of D2D links.
2013	[124]	Resource Allocation for real time services in LTE networks: resource allocation using cooperative game theory and virtual token mechanism.	Cooperative game, bankruptcy game, Shapley value, virtual token mechanism, EXP-RULE algorithm, M-LWDF algorithm	Bandwidth	This work proposes a two-level resource allocation scheme to distribute bandwidth fairly and to improve the QoS for real time and non-real time multimedia services in LTE downlink system combining cooperative game theory, virtual token mechanism, the EXP-RULE algorithm and Modified-Largest Weighted Delay Firs (M-LWDF) algorithm. Both algorithms EXP-RULE and M-LWDF have been modified to use a virtual token mechanism to improve their performance, giving priority to real time flows.
2013	[125]	Resource allocation with flexible channel cooperation in cognitive radio networks.	Cooperative game, Nash bargaining game	Power, channel, spectrum	This work proposes a Nash cooperative bargaining game framework for resource allocation problem in an OFDMA based CR network. The proposed work optimize the allocation of channel, spectrum, and power between primary and secondary networks, in both decentralized and centralized settings.
2013	[126]	Stackelberg game based interference management for two-tier	Stackelberg game	Power, Spectrum, interference	This work studies an uplink interference management problem in a spectrum-sharing femtocell network. The algorithm jointly maximizes the utility of macrocell base station and the individual utility of femtocell users.

		femtocell networks			
2013	[127]	Stackelberg game for spectrum reuse in the two-tier LTE femtocell network.	Stackelberg game	Spectrum, interference	This work proposes a Stackelberg game to study the spectrum reuse in the two-tier LTE femtocell network. In order to improve the network performance, the FBSs are encouraged to provide services to nearby macro-cell users, and the MBS releases a fractional spectrum to the FBSs for avoiding cross-tier interference in return.
2013	[128]	Toward cloud-based vehicular networks with efficient resource management.	Non-cooperative game	Bandwidth, Spectrum, VM	This work proposes a non-cooperative game framework to study cloud resource allocation and virtual machine migration for effective resource management in this cloud-based vehicular network. In fact, cloud computing is integrated into vehicular networks such that the vehicles can share computation resources, storage resources and bandwidth resources.
2013	[129]	Tutorial 1: Radio resource management in small-cell networks	Cooperative game, clustering, semi-centralized algorithm	Power, Interference	This work provides a comprehensive overview of the different proposed techniques for resource allocation, the interference management and power control in small cell networks. It proposes an approach based on cooperative game, clustering and semi-centralized computation
2014	[130]	A multi-cell adaptive resource allocation scheme based on potential game for ICIC in LTE-A.	Potential game	Power, sub-channel	This work proposes a multi-cell adaptive distributed resource allocation algorithm based on potential game for ICIC in LTE-A. The allocation of the sub-channel and the transmitted power is optimized dynamically according to a novel pricing factor.
2014	[131]	Coalitional games for resource allocation in the device-to-device uplink underlaying cellular networks.	Cooperative game	PRB, interference	This work proposes a cooperative game framework to deal with the uplink resource allocation problem for multiple D2D and cellular users combing different transmission modes, mutual interferences and resource sharing policy in a single utility function.
2014	[132]	Coalitional games with overlapping coalitions for interference management in small cell networks.	Cooprative game, overlapping coalition	Channel, spectrum, interference	This work proposes a cooperative game with overlapping coalitions to deal with the problem of interference management in an OFDMA two-tier small cell network, so as to optimize their sum-rate, while cooperatively satisfying their maximum transmit power constraints and optimizing the trade-off between the benefits and costs associated with cooperation.
2014	[133]	Collaborative algorithm for resource allocation in LTE-Advanced relay networks	Cooperative game, PFS	PRB	This work proposes a Collaborative Algorithm based on the Market Game theory to address the problem of Resource Allocation for LTE-Advanced Relay network, which helps in resolving the challenge in resource allocation, and optimizes transmission for cell-end users and resource-starved users on the network, thus improving the network capacity and the system spectral efficiency.
2014	[134]	Cooperative Distributed Optimization for the Hyper-Dense Small Cell Deployment	Cooperative game	Power, PRB, Carrier	This work proposes a cooperative distributed radio resource management algorithms for time synchronization, carrier selection, and power control for hyper-dense small cell deployment.
2014	[135]	Distributed interference-aware energy-efficient resource allocation for device-	Non-cooperative game	Power, Channel, interference	This work proposes a distributed interference-aware energy-efficient resource allocation algorithm to maximize each UE's energy efficiency (EE) subject to its specific quality of service (QoS) and maximum transmission power constraints. It models the resource allocation problem as a non-cooperative game, in which

		to-device communications underlaying cellular networks.			each player is self-interested and wants to maximize its own EE. Both of the D2D UEs and cellular UEs are taken into consideration. An iterative optimization algorithm is proposed to find the Nash equilibrium
2014	[136]	Distributed resource and power allocation for device-to-device communications underlaying cellular network.	Stackelberg game	PRB, power	This paper proposes a distributed resource allocation and power control scheme based on stackelberg game framework to improve network capacity in D2D communications networks. The system aims to maximize the number of underlay D2D users while guaranteeing QoS of the prioritized cellular users.
2014	[137]	Dynamic Backhaul Resource Allocation: An Evolutionary Game Theoretic Approach	Asymmetric game, evolutionary game	Bandwidth	This work proposes an asymmetric evolutionary game for the backhaul-resource allocation problem, encountered from the side of the Passive Optical Network (PON). The game models the interactions between the subscribers and the base station.
2014	[138]	Efficient radio resource management algorithms in opportunistic cognitive radio networks.	Auction game	Spectrum	This paper proposes two radio resource management (RRM) algorithms based fixed-price and an auction game, enabling for the opportunistic exploitation of TVWS in a centralized CR networking architecture.
2014	[139]	Energy-efficient resource allocation in full-duplex relaying networks.	Stackelberg game	Power, Bandwidth	This work proposes an energy-efficient joint bandwidth sharing and power allocation in full-duplex relaying (FDR) systems, based on a tree-stage Stackelberg game. Then an iterative algorithm is proposed to obtain the Stackelberg equilibrium solution.
2014	[140]	Energy-efficient resource sharing for mobile device-to-device multimedia communications.	Cooperative game	Power, Spectrum	This work proposes a non-transferable distributed cooperative game based on the merge-and-split rule and the Pareto order to deal with the problem of energy-efficient uplink resource sharing over mobile D2D multimedia communications underlaying cellular networks with multiple potential D2D pairs and cellular users.
2014	[141]	Femtocell access strategies in heterogeneous networks using a game theoretical framework.	Potential game	Power, Channel Scheduling	This work proposes a two-cell selection based potential game for distinct scenarios to formulate the behaviors of nonsubscribers within the transmission range of femtocell base station.
2014	[142]	Game theory based energy-aware uplink resource allocation in OFDMA femtocell networks.	Non-cooperative game, sub-modular game	Power, channel, interference	This work proposes an energy efficient uplink power control and sub-channel allocation in two-tier femtocell networks, using super modular game to maximize energy efficiency and to reduce the co-channel interference. The proposed algorithm introduces a convex pricing scheme to curb their selfish behavior.
2014	[143]	Game theoretic framework for power control in intercell interference coordination	Non-cooperative game, Sub-modular Game	PRB, power	This paper proposes a sub modular game of the power level selection process of resource blocks (RB to addresses the problem of ICIC in the downlink of cellular OFDMA systems. Then it proposes a semi distributed algorithm based on best response dynamics to attain the NEs of the modelled game.
2014	[144]	Joint Interference Mitigation and Power Allocation for Multi-Cell LTE Networks: A Non-Cooperative Game Approach	Non-cooperative game, SFR	PRB, power, interference	This work proposes a non-cooperative game power allocation (NGPA) scheme for interference mitigation in LTE uplink employing conventional soft frequency reuse (SFR) scheme to model inter-cell interference.

2014	[145]	Network access for M2M/H2H hybrid systems: a game theoretic approach	Non-cooperative game	PRB, RACH procedure	This work proposes a game-theoretic framework, which divides its random access resources into three groups: for human-to-human (H2H), for machine-to-machine (M2M), and for the hybrid usage. Under this framework, the Nash Equilibrium (NE) guarantees the system throughput by adaptively redistributing the traffic loading
2014	[146]	Optimal Power Allocation and User Scheduling in Multicell Networks: Base Station Cooperation Using a Game-Theoretic Approach	Cooperative game, potential game	Power, scheduling, channel, interference	This work proposes a BS coordination approach for intercell interference mitigation in the OFDMA based cellular networks based cooperative potential game. It jointly considers spectrum efficiency, user fairness, and service satisfaction. Interference graph is applied here to capture and analyze the interactions between BSs.
2014	[147]	Power allocation for D2D communications in heterogeneous networks	Stackelberg game, non-cooperative game	Power, price	This work proposes a non-cooperative stackelberg game framework for power allocation problem of D2D communications in heterogeneous macrocell/femtocell networks to improve the performance of the whole system. Prices and transmit power are adjusted to maximize utility obtained by base stations and D2D pairs respectively.
2014	[148]	Replicator dynamics for distributed Inter-Cell Interference Coordination	Potential game	PRB	This work proposes a potential game for resource selection process to addresses the problem of ICIC in the downlink of LTE systems, then it puts forward a fully decentralized algorithm based on replicator dynamics to attain the pure NEs of the modelled game.
2014	[149]	Resource allocation for intercell device-to-device communication underlaying cellular network: A game-theoretic approach.	Non-cooperative game, Repeated game, static game	PRB, rate	This work proposes a repeated game model to address the resource allocation problem for intercell D2D communications underlaying cellular networks, where D2D link is located in the overlapping area of two neighboring cells. Here the BSs are competing resource allocation quota for D2D demand.
2014	[150]	Resource Allocation for Device-to-Device Communication in LTE-A Network: A Stackeberg Game Approach	Stackelberg game	PRB, power	This work proposes an algorithm based Stackelberg game which joints power control and resource allocation and concentrates on reusing the uplink resource by grouping eNB and D2D UEs (D-UEs) to form the seller-buyer pair. The proposed method can lead to a good trade-off between the sum throughput and the rate of D2D pairs.
2014	[151]	Resource allocation in D2D communication - A game theoretic approach	Stackelberg game	Channel, BS-centric allocation	This paper proposes a BS-centric system scheme for D2D resource allocation using a stackelberg game theory. Then, it focuses on the Unknown Channel Quality(UCQ) problem which exists uniquely in D2D communication. A contract-based mechanism with the linear search algorithm is proposed to resolve the UCQ problem by maximizing the profit of the BS, obviating the deviation of UEs, and eliminating the incentive of UEs to report untruthfully with designed service contracts.
2014	[152]	RRM strategy based on throughput and fairness in LTE-A relay system	Zero-sum game	PRB	This paper proposes an algorithm based on the "balanced-allocation" principle, using normalized zero game and considering user SINR dispersion degree as the main parameter. The proposed algorithm improves the fairness of the center users and edge users.

2014	[153]	Transmission scheduling and Game Theoretical Power Allocation for Interference Coordination in CoMP	Non-cooperative game, Water-Filling game	Power, scheduling	This work proposes a framework to increase the total downlink throughput for all edge users in CoMP based LTE-A networks. It includes a simple and integrated transmission scheduling process based on RSRP and a non-cooperative power allocation game to coordinate inter-CBS CCI. Two transmission-scheduling algorithms (DTS and CTS) were proposed, in which edge users CBSs are scheduled in an integrated process, and the CBSs are dynamically clustered.
2014	[154]	Two-Level Downlink Resource Allocation Scheme Based on Cooperative Game Theory in LTE Networks	Cooperative Game, Nucleolus solution, PFS	Capacity, flow classes, scheduling	This work studies the resource allocation problem in real-time downlink LTE network services problem and it applies a two layer solution that combines a Nucleolus-cooperative game and the Proportional Fair scheduler to distribute flow classes between Users by minimizing the player's dissatisfaction
2014	[155]	Win–win relationship between macrocell and femtocells for spectrum sharing in LTE-A	Stackelberg game	Spectrum, interference	This work proposes a Stackelberg game approach to address the spectrum-sharing problem in a HetNet network in which macrocell and femtocells can simultaneously share the available bandwidth, while avoiding the intra-tier interference and helping the macrocell to offload by expanding the cell range of some femtocells. Indeed the macrocell is selling bandwidths to femtocells in exchange of some victim macro-users to serve, mainly the macro-users who undergo severe interference from the neighbouring femtocells.
2014	[156]	Zone-Based Load Balancing in LTE Self-Optimizing Networks: A Game-Theoretic Approach	Non-cooperative game, Water-Filling game	Power, scheduling	This work proposes a framework to increase the total downlink throughput for all edge users in CoMP based LTE-A networks. It includes a simple and integrated transmission scheduling process based on RSRP and a non-cooperative power allocation game to coordinate inter-CBS CCI. Two transmission scheduling algorithms (DTS and CTS) were proposed, in which edge users and CBSs are scheduled in an integrated process and the CBSs are dynamically clustered and thus BSs are more flexible and environment-adaptive. This cuts down the signalling and management overheads.
2015	[157]	A fast cloud-based network selection scheme using coalition formation games in vehicular networks.	Cooperative game	Power, Bandwidth	This paper proposes a cloud-based network selection scheme using a cooperative game in vehicular networks. The proposed scheme leverages the database maintained in the cloud to assist vehicles on the move to select the best networks. Vehicles are able to make decisions based on the information provided by the cloud in a wider network awareness scope. The proposed game is able to trade-off the network and individual vehicles' performance.
2015	[158]	A joint game-theoretic interference coordination approach in uplink multi-cell OFDMA networks.	Potential game	Power, channel, interference	This work proposes a joint potential game-theoretic approach to perform simultaneously inter-cell interference coordination in uplink multi-cell OFDMA networks where only partial information exchange is involved. In fact, it designs a distributed joint-strategy iterative algorithm to allocate channel and power allocation and to perform user scheduling.
2015	[159]	A novel scheduling algorithm based class-service using game theory for LTE network	Cooperative game	Bandwidth, scheduling	This work proposes a scheduling algorithm on class service using cooperative game theory. The available resources are fairly distributed among classes as proportion, which results in higher fairness level among classes. The users with tightest delay requirements are prioritized.

2015	[160]	A Secure Radio Environment Map Database to Share Spectrum	Markov Decision Process concept, Bayesian game, Stackelberg game	Spectrum	This work proposes a robust and secure database for spectrum sharing in CR network using Markov Decision Process concept and Bayesian Stackelberg game. The solutions facilitate releasing more bandwidth and improves system throughput.
2015	[161]	Achieving spectral and energy efficiencies in multi-cell networks	Non-cooperative game	PRB, power	This work proposes a non-cooperative game framework for the power control and resource allocation to addresses the problem of ICIC in the downlink of multicell OFDMA LTE systems,
2015	[162]	An evolutionary game for distributed resource allocation in self-organizing small cells.	Evolutionary game	Power, Subcarrier	This work proposes an evolutionary game theory (EGT)-based subcarrier and power allocation scheme for small cells underlying a macro cellular network. For the proposed algorithm, the average SINR and data rate are obtained based on a stochastic geometry analysis.
2015	[163]	An operations research game approach for resource and power allocation in cooperative femtocell networks.	Cooperative game	PRB, Power	This paper proposes a resource and power allocation framework, modelled as an operations research game or cooperative game theory, namely the Shapley value and the Nucleolus.
2015	[164]	Contract-Based interference Coordination in Heterogeneous Cloud Radio Access Networks	Cooperative game, contract-based game	PRB, Power, interference	This work proposes a contract-based interference coordination framework to mitigate the inter-tier interference between Remote Radio Heads (RRHs) and macro base stations MBSs in Heterogeneous cloud radio access networks (H-CRANs).
2015	[165]	Distributed Resource Allocation in Device-to-Device Enhanced Cellular Networks	Non-cooperative game, stackelberg game	Power, Spectrum, interference	This paper proposes a decentralized uplink spectrum management for a shared hybrid network consisting of D2D and cellular links, aiming to maximize the total throughput of D2D links with an interference constraint for protecting cellular transmissions. The proposed approach is based a non-cooperative stackelberg game.
2015	[166]	Distributed subchannel allocation for interference mitigation in OFDMA femtocells A utility-based learning approach.	Non-cooperative game	Channel, interference	This work proposes a distributed sub-channel allocation (DSA) for co-tier interference mitigation in OFDMA-based a non-cooperative rate maximization game.
2015	[167]	Energy efficient resource allocation for D2D communication underlaying cellular networks.	Non-cooperative game	Power, channel	This work proposes a non-cooperative game to address the problem of resource sharing in Device-to-Device (D2D) communication underlaying cellular networks. Here mobile users decide their respective transmission power over available RBs with the goal of maximizing their own utility function.
2015	[168]	Energy-aware competitive power allocation for heterogeneous networks under QoS constraints.	Non-cooperative game, equilibrium, fractional programming.	Power, subcarrier	This work proposes a distributed non-cooperative power allocation scheme for maximizing energy efficiency in the uplink of OFDMA-based HetNets where a macro-tier is augmented with small cell access points.

2015	[169]	Energy-efficient resource allocation for D2D communications in cellular networks.	Cooperative game	Power, Channel	This work proposes a joint energy-efficient sub-channel and power allocation problem for D2D links which aims to maximize the minimum weighted energy-efficiency (EE) of D2D links while guaranteeing the minimum data rates. Three resource allocation algorithms with different complexity, namely Dual-Based, Branch-and-Bound (BnB), and Relaxation-Based Rounding (RBR) algorithms are proposed.
2015	[170]	Energy-efficient resource allocation for device-to-device underlay communication.	Auction game	Power, Channel	This work proposes a joint channel and power allocation based combinatorial auction game to improve the energy efficiency of Ues
2015	[171]	Energy-efficient resource block allocation for licensed-assisted access	Nash bargaining game	PRB	This work proposes a joint licensed and unlicensed RB allocation algorithm to achieve EE fairness among different small cell base stations (SBSs) in Licensed-assisted access (LAA) system, based on the Nash bargaining game.
2015	[172]	Game Theory Based Radio Resource Allocation for Full-Duplex Systems	Non-cooperative game, Nash bargaining game	Spectrum, sum rate	This work deals with the problem of joint radio resource allocation for uplink and downlink in the full-duplex system in other term the joint uplink and downlink sum-rate maximization. The algorithm proposed achieves a considerable spectral efficiency gains comparing to half-duplexing.
2015	[173]	Game theory based power allocation in LTE air interface virtualization	Auction game, cooperative game, shapely value	PRB, power	This work proposes a two-stage power allocation scheme in LTE air interface virtualization where radio resources are coordinated by a hypervisor among different virtual operators (VOs). First, VCG auction game is utilized to generate an initial allocation by modelling VOs as bidders for power resources and hypervisor as the auctioneer. Second, Shapley value in coalition game is introduced to adjust the initial power allocation. The adjustment is made according to users' rate requirements to guarantee a fair allocation among users of different VOs.
2015	[174]	Game-Theoretic Approach to Energy-Efficient Resource Allocation in Device-to-Device Underlay Communications	Non-cooperative game	PRB, power, interference	This work proposes a non-cooperative distributed interference-aware energy-efficient resource allocation framework by exploiting the properties of the nonlinear fractional programming. We also analyze the trade-off between EE and Spectral Efficiency (SE) and derive closed-form expressions for EE and SE gaps.
2015	[175]	Game-Theoretic Hierarchical Resource Allocation for Heterogeneous Relay Networks	Hierarchical game, Stackelberg game	PRB, Power, rate	This paper proposes a hierarchical game based on the Stackelberg model to address the resource allocation in heterogeneous relay networks.
2015	[176]	Hybrid Overlay/Underlay Cognitive Femtocell Networks: A Game Theoretic Approach	Cooperative game	Channel, spectrum	This work proposes a subchannel allocation problem for OFDMA-based hybrid overlay/underlay spectrum access mechanism to further improve the performance of cognitive femtocell networks.
2015	[177]	Incentive mechanisms for device-to-device communications.	Stackelberg game, Auction game	PRB, channel	This work proposes a design for incentive mechanisms to encourage users to work under D2D mode. It considers two basic market types, open markets and sealed markets, where users have information of all users or only their own, respectively. It adopts a

					Stackelberg game for open market and an auction game for sealed markets.
2015	[178]	Inter-cell interference coordination based on power control for self-organized 4G systems	Non-cooperative game, Sub-modular Game	Power	This work proposes a non-cooperative game for the power level selection of resource blocks (RBs) to addresses the problem of ICIC in the LTE downlink. Then, it proposes game based on a semi-distributed algorithm based on best power response to reach NEs in a time coherent with the RNTP signalling time.
2015	[179]	Joint cell selection and sub-channel allocation for energy efficiency in small cell networks: A coalitional game	Cooperative game	Channel, Cell Selection	This work proposes a coalitional game to select cell and allocate resources where UEs in the same cell are considered to be in the same coalition. It uses a greedy algorithm to assign a sub-channel for an SUE. Finally, it proposes a distributed algorithm to find stable coalitions.
2015	[180]	Joint mode selection and spectrum partitioning for device-to-device communication: A dynamic stackelberg game.	Stackelberg game, evolutionnary game	Spectrum, Mode selection	This work proposes a dynamic evolutionary- Stackelberg game framework to jointly address the problems of spectrum partitioning and user-controlled mode selection for Device-to-Device Communication.
2015	[181]	Joint Optimization of Resource Allocation and Relay Selection for Network Coding Aided Device-to-Device Communications	Cooperative game	PRB, spectrum, relay selection	This work proposes a joint resource allocation and relay selection based-cooperative game and binary integer linear programming, for network coding assisted D2D communications underlaying the cellular network.
2015	[182]	Joint resource allocation for device-to-device communications underlaying uplink MIMO cellular networks.	Non-cooperative game	Power, channel	This paper proposes a non-cooperative resource allocation framework for the joint self-optimization of channel allocation, power control, and precoding of the D2D communications underlaying uplink MIMO cellular networks.
2015	[183]	Joint scheduling and power control in multi-cell networks for inter-cell interference coordination	Cooperative game, convex optimization	Power, scheduling	This work proposes solutions for the problem of joint power control and scheduling in the framework of ICIC in the downlink of LTE OFDMA-based multi-cell systems combining two approaches to allocate system resources in order to achieve high performance: a centralized approach based on convex optimization and a semi-distributed approach based on non-cooperative game theory.
2015	[184]	Optimal resource allocation in random access cooperative cognitive radio networks.	Bargaining game, cooeprative game	Channel, spectrum	This work proposes an implementation of the CCRN framework as a two-player bargaining cooperative game who bargains for either throughput share or channel access time share.
2015	[185]	Optimal user-centric relay assisted device-to-device communications: an auction approach.	Vickrey–Clarke–Groves game, auction game	Power, relay selection	This work proposes a Vickrey–Clarke–Groves auction based relay allocation mechanism (ARM) and power allocation. It considers user-centric relay assisted D2D communications where D2D users have different evaluations for the significance of every unit of increased data rate.
2015	[186]	Pareto efficient resource matching	Zero-sum game, sub-	PRB, carrier selection,	This work proposes an algorithm based sub-optimal solution using two sided matching game for resource matching in CA based LTE-A 4G networks to find a

		for LTE-A system	optimal solution	MCS selection	Pareto optimal stable point. It considers carrier selection, resource allocation, MCS selection as a single problem and consider both uplink and downlink.
2015	[187]	Performance analysis of Bayesian coalition game-based energy-aware virtual machine migration in vehicular mobile cloud.	Cooperative game, Bayesian game	Channel, Energy, VM	This work proposes Bayesian cooperative game as a service for intelligent context switching of VMs to support the computing and communication services in order to reduce the energy consumption, so that clients can execute their services without a performance degradation.
2015	[188]	Pricing and power control for energy-efficient radio resource management in cognitive femtocell networks	Non-cooperative game	Power, spectrum	This work proposes a win–win solution of energy-efficient radio resource management in cognitive femtocell networks based non cooperative game, where the macrocell tries to maximize its revenue by adjusting spectrum utilization price while the femtocells try to maximize their revenues by dynamically adjusting the transmit power.
2015	[189]	Pricing-based interference coordination for D2D communications in cellular networks.	Non-cooperative game	Power, spectrum, interference	This work proposes A pricing-based joint spectrum and power allocation framework for decentralized interference coordination among device-to-device (D2D) communications and cellular users (CUs), with the quality-of-service (QoS) guarantee.
2015	[190]	Quality-optimized joint source selection and power control for wireless multimedia D2D communication using stackelberg game.	Stackelberg game	Power, source selection	This work proposes a low complexity distributed-Stackelberg game theoretical source selection and power control scheme that enhances the multimedia transmission quality with latency constraints.
2015	[191]	Radio resource allocation and system-level evaluation for full-duplex systems.	Non-cooperative game	Channel, interference	This paper proposes a non-ooperative RRA problem for full-duplex systems that jointly maximize the uplink and downlink sum-rate. The problem is coupled between uplink and downlink channels due to the self-interference.
2015	[192]	Resource Allocation for Cognitive Small Cell Networks: A Cooperative Bargaining Game Theoretic Approach	Cooperative game, Nash bargaining game	Power, channel, interference	This work proposes a joint uplink subchannel and power allocation problem in cognitive small cells using cooperative Nash bargaining game theory, where the cross-tier interference mitigation, minimum outage probability requirement, imperfect CSI and fairness in terms of minimum rate requirement are considered
2015	[193]	Resource Allocation for Device-to-Device Communications As an Underlay Using Nash Bargaining Game Theory	Nash bargaining game	Power, channel	This work suggests a Nash bargaining game for joint channel assignment and power allocation to maximize the utility of cellular users and throughput of D2D pair
2015	[194]	Resource allocation in LTE-Advanced Network: A collaborative market game approach	Market Game	Bandwidth	This work proposes a collaborative resource allocation technique using the Market Game that utilizes the Shapley value solution concept, which is a method, used in the field of Political Economy for fair distribution of resources as exemplified in a welfare state.

2015	[195]	Resource Sharing with Minimum QoS Requirements for D2D Links Underlaying Cellular Networks	Zero-sum game	PRB, D2D link, interference	This work proposes a multi-criteria allocation scheme based on a distributed college admissions game for D2D communication underlying LTE downlink network. It addresses the problem in a scenario where local D2D links compete with each other to access and reuse spectrum resources being scheduled to cellular users. The proposed algorithm incorporates minimum resource requirements of the D2D links, enables QoS while limiting the interference impact on cellular services.
2015	[196]	Strategy-Proof Resource Allocation Mechanism for Multi-Flow Wireless Multicast	Strategic game, water-filling game	PRB	This work proposes a multicast resource allocation mechanism with the designs of the pricing scheme and the weighted water-filling resource allocation. To configure the multicast and achieve optimal resource allocation, the BS may require the feedback of the channel-quality information (CQI) from the users.
2016	[197]	A Mapping Scheme of Users to SCMA Layers for D2D Communications	Cooperative game	Users, D2D Link	This work proposes a mapping scheme of users to Sparse code multiple access (SCMA) layers for D2D communication to maximize the system sum rate, and a coalition game to obtain the solution for this mapping.
2016	[198]	A pareto-optimal approach for resource allocation on the LTE downlink	Nash bargaining game	PRB	This work proposes a fair scheme to allocate RB on the downlink in LTE networks to overcome the path-loss and low bit-rate. It addresses maximizing the overall system throughput while ensuring the fair resource allocation among UEs based on the Nash Bargaining game.
2016	[199]	Cooperative Bandwidth Sharing for 5G Heterogeneous Network Using Game Theory	Cooperative Game, Backwards Induction	Bandwidth, QoS	This work proposes a cooperative game for Bandwidth Sharing in 5G HetNet to optimize the wireless resources allocation corresponding to different situations among different cells. As result, cells can serve more users inside one cell; all users are fair to share the bandwidth according to their request and location. The whole system becomes more flexible and performance has been enhanced.
2016	[200]	Coordinated scheduling via frequency and power allocation optimization in LTE cellular networks	Potential game	PRB, power, scheduling, interference	This work proposes a dynamic solution of the coordinated scheduling and inter-cell interference performing an optimization of frequency sub-band reuse and transmission power in order to maximize the overall network utility. The proposed algorithm is based on a potential game. A meaningful improvement in energy efficiency is obtained.
2016	[201]	Device-to-Device Communication in LTE-Advanced System: A Strategy-proof Resource Exchange Framework	Nash game, Exchange Game	PRB, interference	This work proposes a novel D2D resource allocation framework for an LTE-Advanced system based on the concept of beneficial exchange and game-theoretic analysis. As results, the algorithm significantly mitigates the interference experienced by D2D devices in LTE-Advanced systems.
2016	[202]	Dynamic Resource Allocation and Advertisement Revenue Optimization for TV Over eMBMS	Non-cooperative game, auction game, voting game	Bandwidth	This work proposes a game theory framework to deal with the service provider controlled ad-supported TV service problem. It reports who is watching a specific channel, it gathers the viewership statistics and then it allocates resources to users in real time. Finally, it maximizes the service provider's profits.

2016	[203]	Echo State Networks for Self-Organizing Resource Allocation in LTE-U with Uplink-Downlink Decoupling	Non-cooperative game, Nash equilibrium	Spectrum	This work proposes a non-cooperative game framework that incorporates user association, spectrum allocation, and load balancing. It studies the problem of resource allocation with uplink-downlink decoupling is studied for a small cell network (SCN) that incorporates LTE in the unlicensed band (LTE-U). Here, the users can access both licensed and unlicensed bands while being associated to different base stations. To solve this problem, a distributed algorithm based on the machine-learning framework of echo state networks (ESNs) is proposed.
2016	[204]	Energy-Efficient Resource Allocation for D2D Communications Underlaying Cloud-RAN based LTE-A Networks	Non-cooperative game	Power, channel, interference	This work proposes an energy-efficient resource allocation algorithm through joint channel selection and power allocation design combining the following concepts: distributed remote radio heads, centralized baseband unit pool and a non-cooperative game. It transforms the non-convex optimization problem into a convex one by applying constraint relaxation and nonlinear fractional programming. Finally, it suggests a centralized interference mitigation algorithm to improve the QoS performance.
2016	[205]	Fast converging auction-based resource allocation for QoE-driven wireless video streaming	Auction game, Vickrey-Clarke-Groves game,Vickrey-Dutch auction	PRB	This work proposes an auction-based resource allocation and derives an upper bound on the number of iterations needed for convergence (convergence time for decentralized resource allocation). The proposed game-theory framework is compatible with cross layer optimization approaches, as the resources are abstracted to provide an interface between the application and the lower layers. In addition, it maximizes the overall QoE over all users, while the users are maximizing their own payoff
2016	[206]	Probabilistic Analysis on QoS Provisioning for Internet of Things in LTE-A Heterogeneous Networks With Partial Spectrum Usage	Stackelberg game, Stochastic Geometry theory, heuristic algorithm, backward induction	Bandwidth, interference	This work proposes a two level framework to address the QoS provisioning for IoT in LTE-Advanced HetNets with partial spectrum usage (PSU). It combines the Stochastic Geometry theory to statistically analyze how the unplanned random behaviors of the IoT-oriented FCells impact the user performance, the concept of effective bandwidth (EB) to provide the users with probabilistic QoS guarantee, and a heuristic algorithm named QA-EB algorithm to make the EB determination tractable. Then, it formulates the interplay of resource allocation between the MCells and FCells into a two-level Stackelberg game, where the two parties try to maximize their own utilities through optimizing the macro-controlled interference price and the femto-controlled PSU policy. A backward induction method is proposed to achieve the Stackelberg equilibrium.
2016	[207]	Protocol Design and Game Theoretic Solutions for Device-to-Device Radio Resource Allocation	Stackelberg game	PRB, UCQ	This work proposes a game theory framework to analyze the peculiarity of D2D communication and to overcome the Unknown Channel Quality (UCQ) problem. It investigates two practical D2D resource allocating protocols.
2016	[208]	Resource allocation for M2M-enabled cellular network using Nash bargaining game theory	Nash bargaining game	Power, spectrum, channel	This work models channel assignment and power allocation strategy using the Nash bargaining theory while reconsidering fairness and utility maximization

2016	[209]	Resource allocation using Nucleolus Value in downlink LTE networks	Cooperative game, Nucleolus solution	Bandwidth, QoS, scheduling, Delay	This work suggests a two level scheduler; the first level is responsible for the distribution of resources among classes using the Nucleolus value, and the second level responsible for the intra-class scheduling layer, using the metric of PF for non-real time flows and proposed scheduler for real time flows. The algorithm aims at improving the performance metrics for video services and maintaining in general a satisfactory level of the performance metrics for the other services
2016	[210]	Resource Block Allocation with Carrier-Aggregation: A Strategy-Proof Auction Design	Auction game	PRB	This work proposes a strategy-proof auction approach with a greedy resource allocation algorithm to carrier aggregation design in an LTE-Advanced system
2016	[211]	Rethinking Mobile Data Offloading for LTE in Unlicensed Spectrum	Nash bargaining game	Spectrum	This work proposes to transfer Wi-Fi users to the LTE-U network and simultaneously allocate some unlicensed spectrum to LTE-U using the Nash bargaining solution and thereby a win-win strategy is developed. It investigates three different user transfer schemes according to the availability of channel state information (CSI): the random transfer, the distance-based transfer, and the CSI-based transfer. In each scheme, the minimum required amount of unlicensed resources under a given transferred user number is analysed.
2016	[212]	Rethinking mobile data offloading in LTE and Wi-Fi coexisting systems	Nash bargaining game	Spectrum	This work proposes to transfer Wi-Fi users to the LTE-U network and simultaneously allocate some unlicensed spectrum to LTE-U using the Nash bargaining solution and thereby a win-win strategy is developed.
2016	[213]	Two-level game for relay-based throughput enhancement via D2D communications in LTE networks	Stackelberg game, cooperative game	Power, spectrum, Relay selection	This work proposes a two-level game to jointly solve the problem of relay node selection power allocation and spectrum allocation using stackelberg and coalition game
2016	[214]	Uplink resource management in 5G: when a distributed and energy-efficient solution meets power and QoS constraints	Non-cooperative game	PRB, power	This paper proposes a decentralized, scalable, and energy efficient radio resource allocation method tailored for the uplink of the upcoming fifth generation (5G) air interface, based on the MIMO physical layer. The proposed solution elaborates on a game-theoretical approach, which aims at maximizing the energy efficiency of mobile terminals, while guaranteeing the respect of average data rates and power consumptions constraints.
2016	[215]	Virtualization Framework and VCG Based Resource Block Allocation Scheme for LTE Virtualization	Auction game	PRB	This work proposes a Wireless Network Virtualization (WNV) framework for RB allocation problem in LTE by adopting the Vickrey-Clarke-Groves (VCG) and auction games concepts.

Table 2: Review of previous researches using GT in the optimization of radio resource allocation in LTE/LTE-Advanced
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5.2. Discussion and survey of RRAOL using GT as a Field of Research

5.2.1. Evolution of research in RRAOL using GT

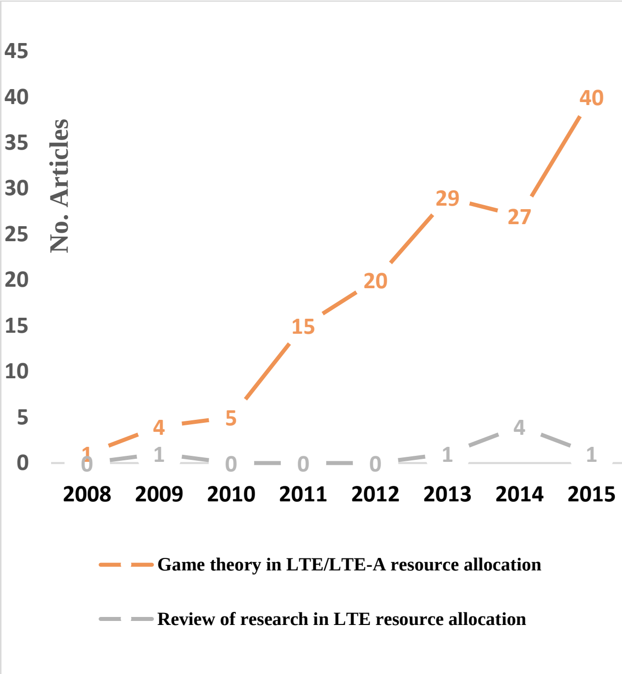


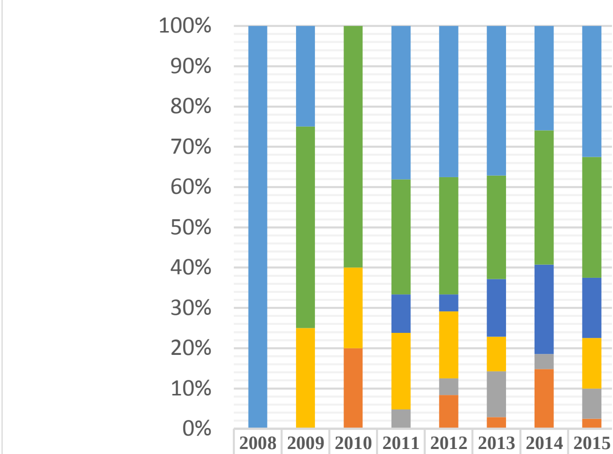
Figure 8: Comparison between RRAOL-review and RRAOL-GT

<u>About RRAOL using GT :</u>
Chart (Figure 7) shows a fast growth of game theorem use in RRAOL research.
<u>- About reviews on RRAOL:</u>
Most of reviews on RRAOL as a Field of research were published starting from 2013. The half of these reviews was published in 2014 only.

5.2.2. Using GT in RRAOL

The charts (Figure 8 and Figure 9) give a GT taxomony with the percentage of use of each game type in last years.
During LTE-R8/R9/R10 (till 2012), most of articles used Non-cooperative/cooperative games. In fact, those two type of game are the most used in all scientific field. In addition, most of research combine the cooperative/non-cooperative game with other type of game. The choice of the game is based on many factors and specially the selfishness of users and the competitiveness of service providers.

In general, 31% of articles used non-cooperative games and 34% used cooperative games (Figure 9).



	2008	2009	2010	2011	2012	2013	2014	2015
Cooperative GAME	1	1	0	8	9	13	7	13
Non-cooperative GAME		2	3	6	7	9	9	12
Stackelberg GAME				2	1	5	6	6
bargaining GAME		1	1	4	4	3		5
Auction GAME				1	1	4	1	3
Potential GAME			1		2	1	4	1

Figure 7: *The use of different type of game in RRAOL-*

In 2011, and with the new concepts CR/HetNet, Stackelberg game start to be used due to its feature. In fact, this type of game is used when two firms compete sequentially on the quantity of output they produce of a homogeneous good. This characteristic fit the HetNet and CR cases.
The communication trend could give some explanation (Figure 10):
Networking has switched from the centralized telephone network to the decentralized Internet (scalability reason) [216]: Decentralization factors (selfish users, competitive SP, etc).

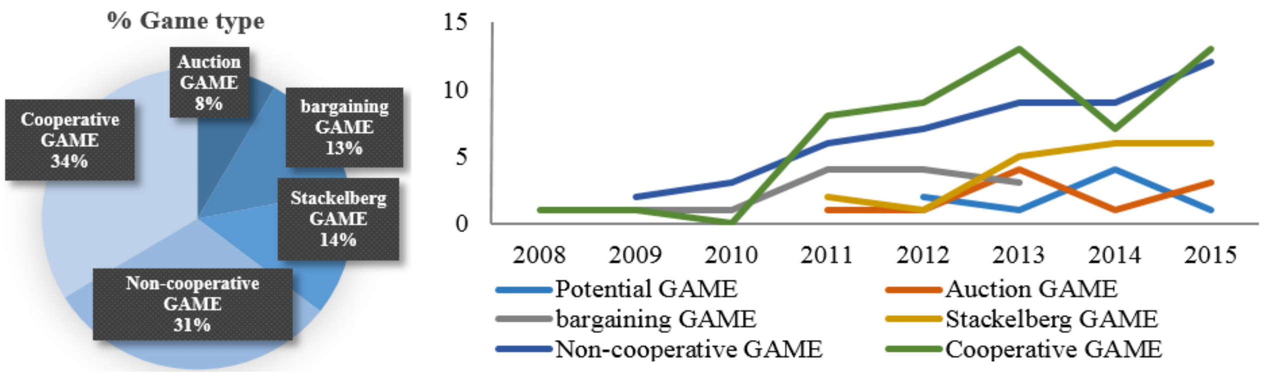


Figure 9: A comparison of the use of different type of game theory during 2008-2012

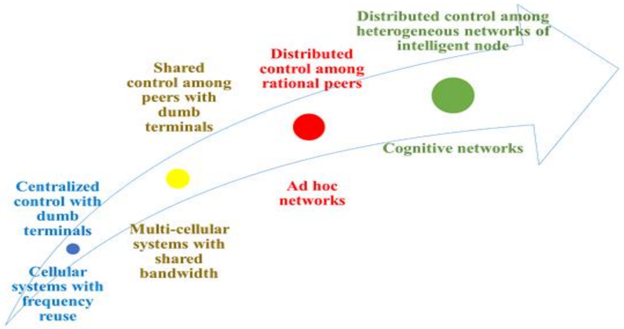


Figure 10: Communication trend vs Distributed Intelligence in Networks [216]

5.2.3. Areas of Research in RRAOL using GT Identified in the Literature Review

Our review could identify five general categories that captured the major themes found throughout the literature and seemed to reflect the trends of research in RRAOL using GT: (1) PRB/ Channel/ subcarrier, (2) Bandwidth/ Spectrum/ rate/ capacity, (3) Power and energy saving, (4) Interference management, (5) Scheduling/selection (table 3).
The categories were derived from the analysis of the articles identified in our review (table 2) where an article could not be assigned necessary to only a single category; if the content of articles fell into more than one category it was placed into the one/two categorie(s) that was/were most relevant. Of course, the five categories are to a certain extent very correlated from a technical point of view!

LEVEL	2008	2009	2010	2011	2012	2013	2014	2015	2016	TOTAL
PRB/ Channel/ subcarrier	1	3	1	6	9	14	18	28	10	90
Bandwidth/ Spectrum/ rate/ capacity		2	4	5	7	21	9	14	9	71
Power and energy	1	2	3	6	13	18	15	24	5	87
Interference	0	1	1	1	7	7	7	9	4	37
Scheduling selection	0	1	1	4	3	10	8	11	7	45
Total	2	9	10	22	39	70	57	86	35	330

Table 3: Areas of Research in RRAOL-GT

If so, the trend of the research was somehow similar for all categories over time between 2008 and 2015. However, according the statistics, we could highlight the degree of importance in RRAOL of the 1st category (i.e. channel, Subcarriers and Resource allocation) as compared to the other categories. (Figure 11).

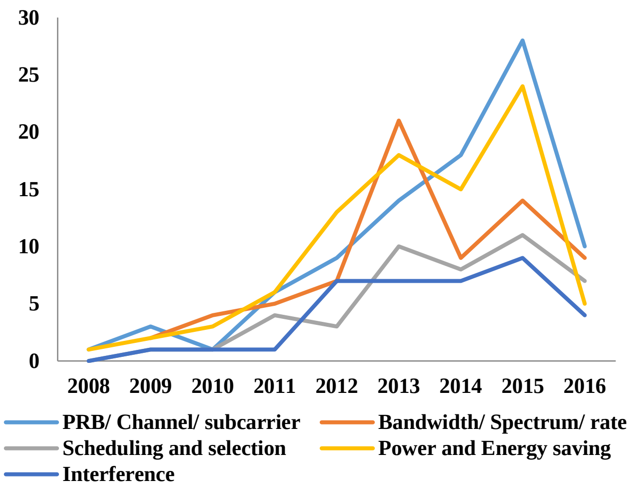


Figure 11: Trends of Research in RRAOL-GT

For research in improvements of the bandwidth/Users rate issues, cooperative games and non-cooperative games were equally used.

5.3. Examples of the GT application in the LTE-A resource management

In this section, we will give, in detail, some examples of the application GT in the LTE-A resource management problem in both directions downlink and uplink that we will try to combine, improve, generalize and accommodate it to our future work.

5.3.1. Uplink direction

(a) *Model*

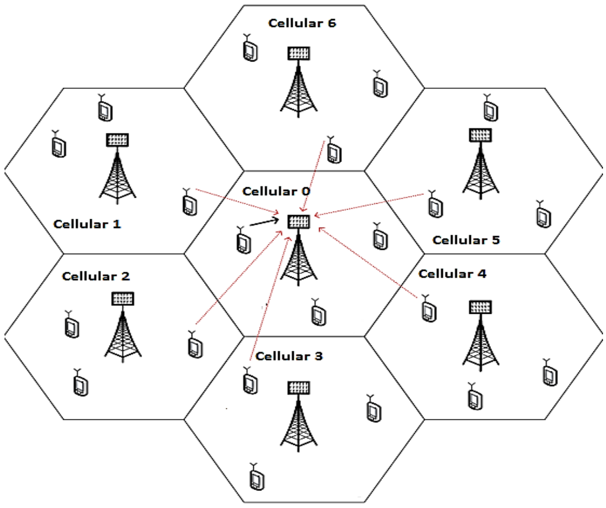


Figure 12. Hexagonal cellular system

Based on the work of [217] and [72], this paper will give an example of non-cooperative games of subcarrier allocation and transmit power control aiming at maximizing the users' SINRs and, most notably, the users' energy efficiency and admitting a Nash equilibrium points NE.
Consider an OFDMA hexagonal cellular system as shown in Figure 12 (it can be denoted as C_0), where N users share L subcarrier in the uplink OFDMA systems and suffer from co-channel interference imposed by users of M cellular around it, due to full frequency reusing. Each subcarrier can only be allocated to one user in each cell. Therefore, M users share the same subcarriers l (S_ℓ), used by the user i (u_i) in C_0, to deliver their information at the same time, and this applies to all subcarrier in the system. Consequently, these M users impose inter-cell interference on $\mathrm{u_i}$ in C_0. Neglecting the large-scale fading effect we only take into account the 6 adjacent cellular so M=6. We assume that the channel is considered flat during resource block duration. Let's define the signal to interference plus noise ratio (SINR) on the ℓ^{th}subcarrier of $\mathrm{u_i}$ in C_0 as following:

$$\gamma_{i,\ell} = \frac{h_{i,\ell}^{(0)} \cdot p_{i,\ell}^{(0)}}{N_0 + \sum_{j=1}^{6} h_{k,\ell}^{(j)} \cdot p_{k,\ell}^{(j)}}; i = 1, 2 \dots, N;\ \ell = 1, 2 \dots, L \qquad (1)$$

Where $h_{i,\ell}^{(0)}$, : $p_{i,\ell}^{(0)}$ denote the i^{th}user's channel gain and transmit power on the ℓ^{th}subcarrier, respectively. $h_{k,\ell}^{(j)}$, $p_{k,\ell}^{(j)}$ are the interference channel coefficient and power of interfering $\mathrm{u_k}$ in C_j. And N_0 is the power spectral density of AWGN on the ℓ^{th} subcarrier of $\mathrm{u_i}$.
Let's denote Γ_i the set of subcarriers allocated to the i^{th}user and P_i^{max} is i^{th}user's constraint of transmit power. Using the Shannon-Hartley theorem, the rate of $\mathrm{u_i}$ on the ℓ^{th} subcarrier

can be defined as:

$$R_{i,\ell} = log(1+\gamma_{i,\ell}) \quad (2)$$

Therefore, we can denote the sum rate of the i^{th} user:

$$R_i = \sum_{\ell \in \Gamma_i} log(1+\gamma_{i,\ell}) \quad (3)$$

$$\text{subject to } \sum_{\ell \in \Gamma_i} p_{i,\ell}^{(0)} \leq P_i^{max}, R_i \leq R_i^{Max}, \forall i \in N,$$

$$p_{i,\ell} \geq 0 \;, \ell \in \Gamma_i$$

(1) Subcarrier allocation**:**

Subcarrier allocation is the main part of an OFDMA RRM algorithm. So in general case the algorithm decides first the number of subcarriers that must be allocated to a user and then decides which specific subcarriers to assign to the new user. There are many algorithms for subcarrier allocation for multi-cellular OFDMA networks, namely coordinated, sequential, random and cell splitting technique.

The authors in [217] denote the normalized channel gain for the i^{th}user in the ℓ^{th} subcarrier as:

$$q_{i;\ell} = \frac{h_{i,\ell}^{(0)}}{\sum_{j \in \Gamma_i} h_{i,j}^{(0)}} \quad (4)$$

To ensure the maximum of $q_{i,\ell}$, each subcarrier should be exclusively allocated to one user aiming to acquire the relative importance among all subcarriers of all users. Consequently, the channel condition can be considered as the basic term to optimize the subcarrier allocation and the near-far effect can be overcome. Therefore, fairness is possible to be achieved.

(2) Power allocation:

After allocating subcarriers to users next step will focus on power allocation algorithm aiming at maximizing each user's sum rate R_i. In this section, we will give two different algorithms with two different utility functions $\mho_i$.

Moreover, both algorithms introduce the same pricing function C_i for each user in order to ensure fairness and reduce the impact of the near-far effect, by punishing users with good channel conditions more than users with hostile channel conditions.

$$C_i = a_i . \sum_{\ell \in \Gamma_i} h_{i,\ell}^{(0)} . p_{i,\ell}^{(0)} \quad (5)$$

a_i is the i^{th}users' pricing factor

As we can notice, the channel gain is present in the pricing function which is due to the importance of path attenuation in the process of determining of the cost introduced by the interfering users.

(b) *Game formulation:*

(1) First solution [72]

For each user, the optimal goal is to minimize the gap between the maximum sum rate R_i^{Max} and the sum rate of the i^{th}user.

$$\mho_i = \left(R_i^{Max} - \sum_{\ell \in \Gamma_i} R_{i,\ell}\right)^{1/2} \quad (6)$$

Here the game is modelled as:

$$J_i = \underset{P_i}{argmin} \begin{pmatrix} R_i^{Max} \\ - \sum_{\ell \in \Gamma_i} R_{i,\ell} \end{pmatrix}^{1/2} + a_i . \sum_{\ell \in \Gamma_i} h_{i,\ell}^{(0)} . p_{i,\ell}^{(0)} \quad (7)$$

$$subject\ to$$

$$\sum_{\ell \in \Gamma_i} p_{i,\ell}^{(0)} \leq P_i^{max}, \qquad R_i \leq R_i^{Max}, \forall i \in N$$

Where P_i^{max} is the i^{th}user's peak value of transmitting power.

And the next equation is the first derivative of J_i:

$$\frac{\partial J_i}{\partial R_{i,\ell}} = -\frac{1}{2}\left(R_i^{Max} - \sum_{\ell \in \Gamma_i} R_{i,\ell}\right)^{1/2} + ln\, 2 \frac{a_i h_{i,l}^{(0)}}{h_{i,l}^{(0)}} \Big(N_0 + \sum_{j=1}^{6} h_{j l,l}^{(j)} p_{j l,l}^{(j)}\Big) 2^{R_{i,l}} \quad (8)$$

(2) Second solution [217]

Here the utility function is an *arc tangent*-based function:

$$\mho_i = arctan(R_i) = arctan\left(\sum_{\ell \in \Gamma_i} R_{i,\ell}\right) \quad (9)$$

The game is modelled as:

$$J_i = \mho_i - C_i = arctan\left(\sum_{\ell \in \Gamma_i} R_{i,\ell}\right) - a_i . \sum_{\ell \in \Gamma_i} h_{i,\ell}^{(0)} . p_{i,\ell}^{(0)} \quad (10)$$

$$subject\ to$$

$$\sum_{\ell \in \Gamma_i} p_{i,\ell}^{(0)} \leq P_i^{max} \quad p_{i,l} \geq 0\ \forall i \in N, \ell \in \Gamma_i$$

And the next equation is the first derivative of J_i:

$$\frac{\partial J_i}{\partial R_{i,\ell}} = \frac{1}{1+R_{i,l}^2} - a_i\, ln\, 2 \left(N_0 + \sum_{j=1}^{6} h_{j l,l}^{(j)} p_{j l,l}^{(j)}\right) 2^{R_{i,l}} \quad (11)$$

Therefore, thanks the NE proprieties defined previously and theorems 1 and 2, both authors proves the existence of NE which led them to the following formulation of the i^{th}user's power:

$$p_{i,l}(n) = \frac{N_0 + \sum_{j=1}^{6} h_{k,l}^{(j)} p_{k,l}^{(j)}}{h_{i,l}^{(0)}} \left(2^{R_{i,l}(n-1)} - 1\right) \quad (12)$$

Where n is the iterative number.

(c) *Algorithm*

Both solution admit the same algorithm but different result in simulation due to difference of utility function, the algorithm is:

1) For each unallocated subcarrier ℓ and user i, determine the normalized channel gain $q_{i;\ell}$ by equation (4), and initialize subcarrier set Γ_i of the i^{th}user.

2) Choose $(i^*, \ell^*) = arg_{i,\ell} \max\ q_{i;\ell}$, then allocate $s_{\ell^*}$to u_{i^*}

3) Repeat Step (2) until every subcarrier has been allocated.

4) Initialize the i^{th}user power allocation array respectively.

5) Update each user's power allocation array according to equation (13) and (8) for the first solution or (11) for the second solution. Repeat Step (5) until convergence is reached.

(d) *Performance evaluation of both proposed solution:*

After simulation the author of [72] conclude that *arc tangent*-based Algorithm acquires better performance than *argmin*-based algorithm in terms of each user's sum rate. Furthermore, it can achieve a more desirable performance on fairness (due to adopting the pricing function) and decrease the near-far effect. Besides, further users can benefit more than near users. Nevertheless, it consumes more power for compensation to derive a higher. And finally, it satisfies the convergence condition and it has a low complexity.

The author of [218] follow in the footsteps of [48], using the *argmin* function and the price function, but he adopts a single cell OFDMA and gives a new utility function based on power efficiency which improve the rate of users and reduce the transmitted power. Then, he proposed a joint subcarrier and power allocation algorithm by using KKT (Karush–Kuhn–Tucker) condition.

In both solutions, authors consider one cellular rather than the whole system, which is like a local optimization of each cellular. In future work, we will extend it to a global multi-objective optimisation taking into account the whole system.

5.3.2. Downlink

(a) *Model*

In this section, we focus on the downlink direction issues stated in [4], therefore we introduce the notion of services class. In fact, in order to avoid starvation of bandwidth corresponding to physical resources for low priority service classes, and also to facilitate the scheduling and the allocation of resources while guaranteeing an exceptional QoS to end user, LTE-A defines a strict requirement for services classes that we should took into consideration while scheduling. Therefore, [4] suggests a cooperative bargaining game based on the divide-and-conquer concept, where service classes are split into inter-class (sorted out and allocated bandwidth resource) and then intra-class (arranged with priority on a packet delay basis for channel access).

At each TTI, UE reports their instantaneous downlink SNR to eNodeB station which is used to calculate the user *i*'s data rate for *j-th* RB at time t as follows:

$$r_{i,j}(t) = \frac{n\_bits}{symbol} \times \frac{n\_symbols}{slot} \times \frac{n\_slots}{TTI} \times \frac{n\_subcarrier}{RB} \quad (13)$$

Where *n_bits*, *n_symbols*, *n_slots* and *n_subcarrier* are the number of bits, number of symbols, number of slots and number of subcarriers; respectively.

The path loss and fading effect are assumed to remain constant throughout the duration of the RB. The gain of channel at time *t* for user *i* on *j-th* RB as a function of the losses is calculated as:

$$C_{Gain_{i,j}}(t) = 10^{(\frac{path\_loss}{10})} \times 10^{(\frac{fading}{10})} \quad (14)$$

This determines the achievable instantaneous downlink SNR that is reported to eNodeB station as follows:

$$SNR_{i,j}(t) = \frac{P_{total} \times C_{Gain_{i,j}}(t)}{N(N_o + I)} \quad (15)$$

Where P_{total} is the total power with which eNodeB station transmits to UE in the downlink direction, and N is the total available RBs, while I refers to the neighbouring cell interference and finally N_o is a measure of thermal noise.

The game here is a set of pairs [N, u], where $N = \{1,2, \dots n\}$ is a finite players set and u is the utility function, which represents user's degree of satisfaction for a particular service class as a function of QoS constraints. The work adopts a game based transfer of benefits considering only the physical RB dimensions and using the sigmoid utility from [218]:

$$u(d) = x_i \left\{\frac{1}{1+e^{-t_i(d-\sigma_i)}} - y_i\right\} \quad (16)$$

$$\begin{cases} x_i = \dfrac{(1+e^{t_i \sigma_i})}{e^{t_i \sigma_i}} \\ y_i = \dfrac{1}{(1+e^{t_i \sigma_i})} \end{cases}$$

Where d is player data rate; t_i *and* σ_i reflects the priority type and intrinsic resource requirement of the service class; x_i and y_i are constants used to normalize utility function.

(b) *Game formulation:*

Let's F be the number of classes and $d = \{1,2, \dots, d_F\}$ represents the data rate in terms of resources that are assigned to class users:

- Players: the services class users $N = \{1,2, \dots n\}$.
- Strategies: the resource assignment vector for users $d = \{1,2, \dots, d_F\}$.
- Payoffs: The sum of user's utility function.
  The payoff revenue for a player n_i, is given as:

$$r_i(d_i) = f_i . U_i(t_i, \sigma_i, d_i) \quad (17)$$

Where f_i is the total number of flows or connections in the class to which n_i belongs. U_i is the utility function and x_i and y_i parameters classify the users service priority. Then the total network profit is given as a function of the payoffs for all users in all classes.

$$P = \sum_{i=1}^{F} r_i(d_i) = \sum_{i=1}^{F} f_i . U_i(t_i, \sigma_i, d_i) \quad (18)$$

Furthermore, and since the purpose is to maximize the total payoff profit of the system and then the system throughput. The author define a maximizing framework as follows:

$$max \sum_{i=1}^{F} r_i(d_i) = max \sum_{i=1}^{F} f_i . U_i(t_i, \sigma_i, d_i) \quad (19)$$

$$Such\ that\ \sum_{i=1}^{F} f_i \times d_i = F \times d_i^T \leq C_p$$

Where C_p is the networks total available system capacity. And d_i^T transpose of d_i.

The following equation define the Pareto optimality; the optimal solution to the game:

$$P(d^*(d_1^*, d_2^*, \dots, d_F^*)) \geq P(d\ (d_1, d_2, \dots, d_F)) \quad (20)$$

Which accepts $(d_1^*, d_2^*, \dots, d_F^*)$ as solution and Pareto optimality if all $d = (d_1, d_2, \dots, d_F)$ satisfy $F \times d_i^T \leq C_p$.

(c) *Solution*

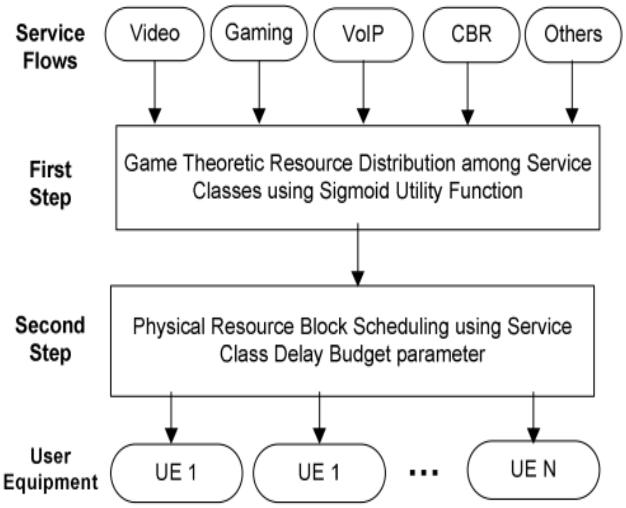


Figure 13. Steps of resource allocation [4].

The resource allocation can be split into two steps as shown in Figure 13:

(1) Steps 1: inter-class resource distribution

Then, to reduce the complexity of finding a Pareto solution the author uses Lagrangian approach defined below:

$$L(d, \lambda) = \sum_{i=1}^{F} f_i U_i(d_i) + \lambda \left(C_p - \sum_{i=1}^{F} f_i \times d_i\right) \quad (21)$$

where λ *is* the Lagrange multiplier that represents the network resource prices and is associated with a linear constraint of capacity. A simplification of the last equation is:

$$L(d, \lambda) = \sum_{i=1}^{F} f_i (U_i(d_i) - \lambda . d_i) + \lambda C_p \quad (22)$$

Since the utility function itself is a sigmoid and not a concave function, the maximum and minimum resource allocation constraints d_{min} and d_{max} can be obtained through utility functions parameter x_i and y_i. Then the equation becomes:

$$L(d, \lambda) = \sum_{i=1}^{F} f_i (U_i(d_i) - \lambda . (d_i - d_{i,min})) + \lambda C_p \quad (23)$$

$$d_i^*(\lambda) = argmax\left[U_i(d_i) - \lambda . (d_i - d_{i,min})\right] \quad (24)$$

A sub-gradient is used to update the dual variable λ and to resolve the Lagrangian:

$$\lambda(m+1) = \left[\lambda(m) - \Delta(m)\left(C_p - \sum_{i=1}^{F} d_i^*(\lambda(m))\right)\right] \quad (25)$$

Where m is he iteration number while $\Delta(m)$ is the step size. Finally, those equations solve network profit optimization problem globally and get optimal resource allocation.

(2) Step 2: intra-class resource distribution:

The intra class user assortment is done on delay measurements as a function of the budget defined by LTE-A standard. The Head of Line (HoL) packet delay is measured for any user *j* in a service class *i* as follows:

$$HoL_j(t) = T_{current}(t) - T_{stamp} \quad (26)$$

Where *t* is time; T_{stamp} is the time of the packet since it arrived at the scheduling queue and while $T_{current}$ is the current packet processing time. The remaining time for scheduling or the delay metric is then the function of HoL:

$$delay_j(t) = \sigma_i - HoL_j(t) \qquad (27)$$

Where σ_i is delay-budget of packet for i.
Finally, the user with the lowest $delay_j(t)$ is chosen.

$$u = arg\,min\,delay_j(t) \qquad \forall user \;\; j \qquad (28)$$

Once u is determined, the mechanism decide which user should transmit on the current RB as shown in Figure 14.

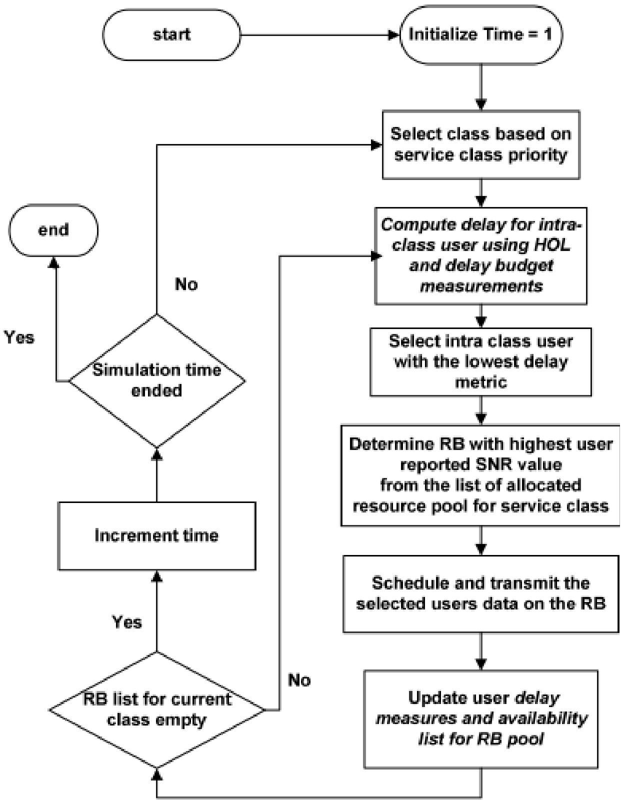


Figure 14. Delay Based Scheduling step [4]

U-delay game (Game Theory with sigmoid utility value characteristic function and a delay based scheduler at the MAC layer) supports both real time and non-real time traffic and it shows better performances in term of throughput, fairness index, packet loss ratio, and system delay, compared to a number of scheduling algorithm in literature such as M-LWDF (Modified Largest Weighted Delay First), PF (Proportional Fair), EXP-RULE (Exponential-Rule), EXP-PF (Exponential-Proportional Fair) [219-222]. Indeed, The PF scheduler allocates resources to users on the basis of channel quality measures of user and the past running throughput the user maintained. The general goal in PF is to maximize aggregated throughput of the system. While the M-LWDF scheduler can serve users with varying QoS requirements. Best channel conditions and the highest Head of Line packet delay of users is used to achieve prioritization of service class. And the EXP-RULE uses a metric measure that increases priority of real time flows as compared to non-real time flows while the delay threshold approaches.

The author gives some simulation results for different services flow type comparing the performances of U-delay, PF, M-LWDF and the EXP-Rule. In this work I will cite only the video services case. In fact, for Video requirements the throughput of the four schemes do not diverge much for an estimated 20 to 30 users, but when more users enter the network, the performance of U-DELAY outweighs the other three schemes with PF showing worst performance (Figure 15).

For Packet Loss Ratio case (Figure 16) U-DELAY maintains a significant space and introduces only around 24% loss percentage for more than 80 users making the performance much visible.

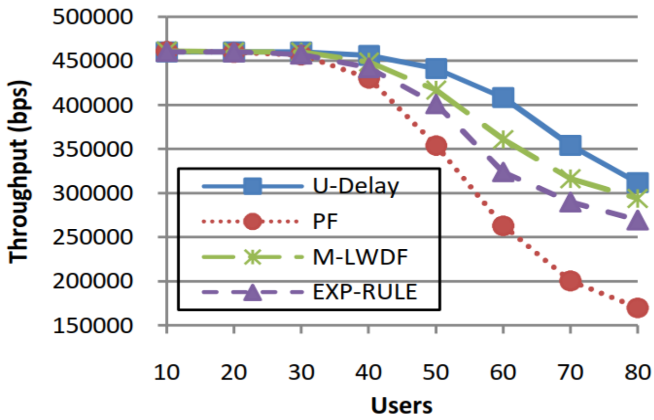


Figure 15: Average throughput for video

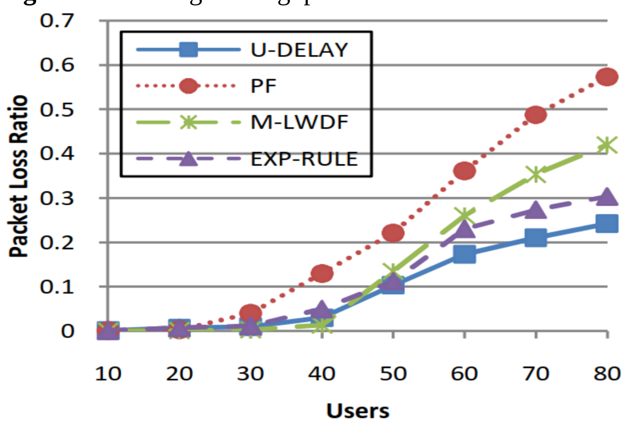


Figure 16: Average Packet Loss Ratio

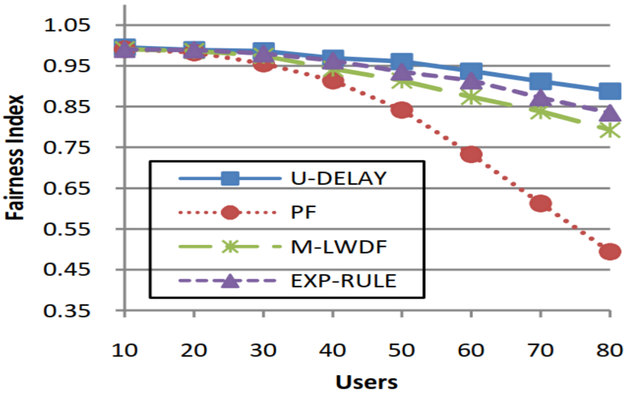


Figure 17: Average Fairness Index

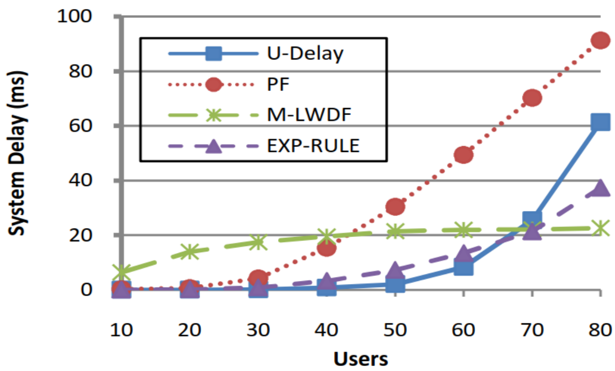


Figure 18: Average System Delay.

In Fairness Index comparison (Figure 17), the use of QoS constraint based Sigmoid Utility function shows proficient results depicting scores as high as 0.88 at 80 system users for U-DELAY while PF scheme score drops to a considerable 0.47 margin.

For system delay measures (Figure 18), U-DELAY performs much better than other schemes for average 60 users but after that the delay of the system cannot be maintained while EXP-RULE and M-LWDF perform better at this stage

6. Future research directions

As we concluded from previous statistics and discussion, RRM takes interest increasingly in several ongoing research works. On the one hand, most of published works in the literature refer to fixed and limited scenarios/samples, subject to restrictions and fixed-ideal conditions (i.e. a limited number of cells, a limited number of users, a small geographical area, a type of traffic, homogeneous services, base stations with the same power, a precise technology and no interaction between different types of networks). Hence, further improvement could be achieved through a real network, which should contain all these above cited real-life conditions and go beyond the usual framework of test. We should try to implement, in this case, a network where all the different heterogeneous technologies and heterogeneous services are randomly integrated as in the real network including the interferences caused by other wireless networks and the competition between them in shared radio resources, especially since the game theory can handle an unlimited number of players under unlimited constraints. To achieve this purpose, especially there will some challenges to be solved, especially simulation issues.

In other hands, the next generation radio mobile 5G will combine 2G, 3G, 4G, wireless local area network (WLAN), optical wireless communication, television white space (TVWS), MTC, het net, multitier communication etc.[223]. This multitier HetNet will also support so many technologies such as ultra-densification network (facing limitation due to backhaul network capacity and backhaul energy efficiency) Millimeter wave (mmWave), massive MIMO, full duplex communication, and energy harvesting techniques, etc. [224-227]. With all these distinct technologies, the existent traditional schemes deem infeasible and inefficient to manage interferences, different resource allocation, and scheduling and energy efficiency [228].

Therefore, there are several clear directions for future research, which could be summarized in the following:

Fiber-Wireless (FIWI) network: the focus is on the aspects of scalability, reliability, architecture designing, QoS guarantying, and energy saving in FIWI network when integrating with emerging technologies such as HetNets, IoT, smart grid, software defined networks (SDN), next-generation passive optical networks (NG-PONs), cloud radio access networks (C-RAN), distributed antenna system (DAS) and next-generation wireless technologies [229].

Tactile internet: the focus is on the optimization of the major pillars of Tactile Internet i.e., RRM (especially wavelength and Bandwidth Allocation), H2H or M2M or Machine-to-Human (M2H) network, cyber sickness for real time transmission, end-to-end latency, ultra-responsive connectivity, reliability, edge and design limit, modulation issues and economic impact. [230-231]

Green communication: the focus is on enhancing the energy-efficient in a (massive) MIMO and OFDMA multi-cell system taking into account interferences [232]

MIMO: the focus is on including the scheduling in the space domain exploiting (massive) MIMO techniques [233-234].

LTE-U: the focus is on analyzing the RRM schemes when two LTE-U operators are competing. It should also be on the interferences caused by the coexistence of WI-FI and LTE-U and on achieving a harmonious coexistence [235-236].

D2D communication networks: the focus is on reconsidering and on reviewing the ordinary-existing RRM scheme when handling D2D networks [237]

Multi-tier and multi-technologies systems: the focus is on

a. Elaborating an advanced interference management scheme for the user-side in the downlink [238].
b. On the design of BS clustering to deal with Cross-tier interference issues [239-244].

Full duplex communication: the focus is on improving the self-interference cancellation scheme to simplify the spectrum management and to help create a denser HetNet [245-247].

Beamforming: the focus is on the beamforming techniques which can improve coverage and network performance for massive MIMO, Multi-tier and ultra-dense network [248-254].

7. Conclusion and perspectives

Resource allocation is one of the big challenges in LTE/LTE-A networks and is one of the most important research topics in wireless communication. In fact, an efficient design of resource allocation schemes is the key to higher performance of a LTE/LTE-A network and in term of differents parameters such as energy efficiency, data rate, power, number of supported user, etc. It's a strategic plan for using available scarce resources among various entity (users, nodes,…) to achieve certain objectives. This becomes more complicated in current wireless network generation based on multi-cell, multi-user, multi-antenna concepts and suffering from multipath fading. This latter issue was the main reason to combine the OFDM technique and the associated access schemes, and therefore to adopt OFDMA and SC-FDMA technique. Therefore, and since game theory take a great part of studies in this last decade, this paper presents a survey of the use of this theory in the LTE-A network and gives some successful examples in both downlink and uplink direction.

LTE advanced Pro (release 13) which is still open to improvement, is an enhancement to LTE-A and a transition to 5G (Release 14). GT or a hybrid solution based on a combination between GT and other mathematical methods would be as efficient approach as solution found by different researchers in LTE/LTE-A field, taking into consideration new constraints (players), new features and new requirements. The transfer of this optimization approach to 5G network will be our next research work.

References

[1] M. Sauter, "From GSM to LTE – An Introduction to Mobile Networks and Mobile Broadband", John Wiley & Sons, Ltd, revised Second edition, 2014,pp 254.
[2] M. Nohrborg, "LTE Overview", Internet, http://www.3gpp.org/technologies/keywords- acronyms/98-lte, [19.04.2016].
[3] G. Fodor, A. Rácz, N. Reider, and A. Temesváry, "Architecture and Protocol Support for Radio Resource Management

(RRM)", in "Long Term Evolution: 3GPP LTE Radio and Cellular Technology", Borko Furht, Syed A, Ahson, Ed,NEWYORK :Taylor and Francic group, 2009, pp 99-153.

[4] S. Ali, M. Zeeshan, "A Utility based resource allocation scheme with delay scheduler for LTE service-class support", in Proceedings of Wireless Communications and Networking Conference (WCNC), 2012, pp, 1450–1455.

[5] J. V. Neumann and O. Morgenstern, "Theory of Games and Economic Behavior", 1944.

[6] G. Song, Y. Li, and L. J. Cimini, "Joint channel- and queue-aware scheduling for multiuser diversity in wireless OFDMA networks," IEEE Trans, Commun,, vol, 57, no, 7, pp, 2109–2121, Jul, 2009.

[7] H. G. Myung, "Introduction to single carrier fdma", 15th European Signal Processing Conference (EUSIPCO 2007), Poznan, Poland, September 3-7, 2007.

[8] P. Kandolcar, M. K. Das, S. Mukherjee, "Telecom White Paper Radio Resource Management Radio Admission Control Radio Bearer Control" , Tata Consultancy Services, India, 2013

[9] L. Badia, A. Baiocchi, S. Merlin, S. Pupolin, A. Todini, M. Zorzi, "On the Impact of Physical Layer Awareness on Scheduling and Resource Allocation in Broadband Multi-cellular IEEE 802,16 Systems", in IEEE Wireless Communications, Vol. 14, NO. 1, FEB 2007, pp. 36-43.

[10] Ajofoyinbo, A.M. "On Ultra Extended Cyclic Prefix in Orthogonal Frequency Division Multiplexing (OFDM) Systems: The Case of LTE Downlink." Communications and Network 2013 (2013).

[11] Anritsu. (2014 April 4). LTE Resource Guide. [Online]. Available:http://web.cecs.pdx.edu/~fli/class/LTE_Reource_Guide.pdf

[12] M. A. Abd El-Gawad , M. M. Tantawy and M. El-Mahallawy, "LTE QoS dynamic resource block allocation with power source limitation and queue stability constraints", International Journal of Computer Networks & Communications (IJCNC) Vol,5, No,3, May 2013.

[13] M. Iturralde, T. A. Yahiya, A. Wei, and A. L. Beylot., "Performance study of multimedia services using virtual token mechanism for resource allocation in lte networks," IEEE 2011 IEEE Vehicular Technology Conference (VTC Fall) - San Francisco, CA, USA, 2011.

[14] R. Zhong, F. Ji, F. Chen, S. Xiong, X. Chen, ''Distributed Subcarrier and Power Allocation for Cellular OFDMA Systems'', DCAI, 2010: 349-356.

[15] G. Piro, L. A. Grieco, G. Boggia, R. Fortuna, and P. Camarda, "Two-level downlink scheduling for real-time multimedia services in LTE networks," IEEE Transactions on Multimedia, vol. 13, no. 5, pp. 1052–1065, 2011.

[16] L. Sivridis, X. Wang, J. Choi, "Impact of varying channel model mixtures on radio resource management for the OFDMA downlink." International Journal of Communication Networks and Information Security 3, no. 2 (2011): 186.

[17] Y. W. Chen , S. C. Ke, "A uplink radio resource allocation scheme for localized SC-FDMA transmission in LTE network'', The Journal of Supercomputing, v.66 n.2, p.670-685, November 2013

[18] K. D. Nguyen, H. N. Nguyen, H. Morino, I. Sasase, "Uplink channel allocation scheme and qos management mechanism for cognitive cellular-femtocell networks." International Journal of Communication Networks and Information Security 6, no. 1 (2014): 62.

[19] M. Abrar, X. Gui, A. Punchihewa, "Low complexity joint subcarrier pairing, allocation and relay selection in cooperative wireless networks." International Journal of Communication Networks and Information Security (IJCNIS) 6, no. 3 (2014).

[20] I. Ahmed, A. Mohamed, "Power control and group proportional fairness for frequency domain resource allocation in L-SC-FDMA based LTE uplink", published in Springer wireless networks journal, volume 21, issue 6, pp 1819-1834, August 2015.

[21] Y. L. Lee, J. Loo, T. C. Chuah, and A. A. El-Saleh, "Multi-objective resource allocation for LTE/LTE-A femtocell/HeNB networks using ant colony optimization", Wirel. Pers. Commun, Aug. 2016.

[22] S. Sun, K.Y. Kim, O. S. Shin, Y. Shin, ''Device-to-device resource allocation in LTE-advanced networks by hybrid particle swarm optimization and genetic algorithm'', Peer-to-Peer Networking and Applications, volume 9, issue 5,pp 945-954, 2016.

[23] A.S. Mohamed, M. Abd-Elnaby, S. El-Dolil, "Self-organized Dynamic FFR Resource Allocation Scheme for LTE-Advanced Relay Based Networks'' Wireless Personal Communications 91, no. 2 (2016): 933-955.

[24] R. Zhu, J. Yang , P. Si "Adaptive Resource Allocation in LTE Downlink Transmission Systems" Mobile and Wireless Technologies 2016 ,Volume 391 of the series Lecture Notes in Electrical Engineering, pp 3-12

[25] Y. C. Wang and S. Y. Hsieh, "Service-differentiated downlink flow scheduling to support QoS in long term evolution," Computer Networks, vol. 94, pp. 344–359, 2016.

[26] Han, Z. and Liu, K.R., "Resource allocation for wireless networks: basics, techniques, and applications", Cambridge university press, 2008 Apr 14.

[27] G. Varoquaux, ''Mathematical optimization: finding minima of functions'', internet: http://www.scipy-lectures.org/advanced/mathematical_optimization/, [JUIN 10, 2016]

[28] A. Gueye "A Game Theoretical Approach to Communication Security" (2011), Electrical Engineering and Computer Sciences University of California at Berkeley. Technical Report No. UCB/EECS-2011-19.

[29] H. WILLIAMS, "The formulation of mathematical programming models", University of Sussex, 03,lEG,4, The Int, Jl of Mgmt Sc, 3(5), 1975.

[30] M. J. Osborne and A. Rubinstein, "A Course in Game Theory", Cambridge, MA: The MIT Press, 1994.

[31] FudeNodeBerg and J. Tirole, "Game Theory", MIT Press, 1991.

[32] R. Gibbons, "A Primer in Game Theory", Prentice Hall, 1992.

[33] W. Saad, T. Basar, Z. Han, D. Niyato and A, Hjorungnes, "Game Theory in Wireless and Communication Networks", Cambridge, JANUARY 2012.

[34] P. R. De Montmort, "Essay d'analyse sur les jeux de hazard", Chez Jacques Quillau, 415 pages, 2 edition, 1713.

[35] P. Walker, "An outline of the history of game theory", University of University of Canterbury, Department of Economics, Working Papers 9504, [Online], Available: http://ideas,repec,org/p/wuk/cantec.

[36] E. Borel, "Algebra and Probability Theory", Proceedings of the Academy of Sciences, in volume terms 184, 1927.

[37] A. Cournot, " Mathematical Principles of the Theory of Wealth", 1838.

[38] F. Y. Edgeworth, " Mathematical Physics", 1881.

[39] J. F. Nash, "Two-person Cooperative Games", Econometrica 21, pages 128–40, 1953.

[40] J. F. Nash, "The bargaining problem", Econometrica 18, pages 155–162, 1950.

[41] J. F. Nash, "Equilibrium points in n-person games", Proceedings of the National Academy of Sciences 36, pages 48–49, 1950.

[42] J. F. Nash, "Non-cooperative games", Annals of Mathematics, pages 286–295, 1951.

[43] H. W. Kuhn, "Contributions to the Theory of Games, II (AM-28) ", Princeton University Press, 1953.

[44] V. Manjula , "Graphs in game theory", International journal of mathematics and computer research, Vol 1 Issue 3, pp 109-114, April 2013.

[45] Z. Cui and M. E. Finkelstein, "Game Theoretical Models in New Product Development", In "Encyclopedia of Business Analytics and Optimization", pp. 1047-1056. IGI Global, 2014.

[46] Y. Tauman, "Coalitional Form", Web, wiki,cc,gatech,edu/theory/index,php/Coalitional_Form, 30 Apr, 2008.

[47] V. Shah, N. Mandayam, D. Goodman, "Power Control for Wireless Data Based on Utility and Pricing," Personal, Indoor and Mobile Radio Commun,, vol,3, pp, 1427-1432, Sep, 1998.

[48] D. E. Charilas, A. D. Panagopoulos, "A survey on game theory applications in wireless networks", Elsevier Computer Networks, Vol, 54, Issue 18, December 2010, Pages 3421-3430.

[49] Archana, B., and T. P. Surekha. "Resource Allocation in LTE: An Extensive Review on Methods, Challenges and Future Scope." Resource, volume 3, no. 2 , octobre 2015).

[50] M. A. Gadam, L. Maijama'a, and I. H.Usman, "A review on resource allocation techniques in downlink lte," Journal of Mobile Communication. pp. 17–23, 2013.

[51] K.I. Pedersen, et.al., "An Overview of Downlink Radio Resource management for UTRAN Long-Term Evolution", in IEEE Communications Magazine, pp. 86-93, July 2009 "

[52] V. Sharma, P.K Chopra, 2014 "A Survey on LTE Downlink Packet Scheduling", International Journal of Advanced Research in Computer and Communication Engineering, Vol. 3, Issue 9.

[53] Usman, I. H., m. A. Gadam, a. A. Garba, and l. Maijama'a. "A review of performance analysis of a downlink lte system using different radio resource allocation schemes (rras)." in proceedings of the multi-disciplinary academic conference on sustainable development, vol. 2, no. 1. 2014.

[54] F.Shams, G. Bacci, M. Luise, ""A survey on resource allocation techniques in OFDM(A) networks"", Computer Networks, vol. 65, no. 2, pp. 129-150, June 2014.

[55] B. Benmammar, A. Amraoui, F. Krief. "A survey on dynamic spectrum access techniques in cognitive radio networks." International Journal of Communication Networks and Information Security 5, no. 2 (2013): 68.

[56] H. Lee, S. Vahid, and K. Moessner, "A survey of radio resource management for spectrum aggregation in LTE-advanced," IEEE Wireless Commun. Surveys Tuts., vol. 16, no. 2, pp. 745–760, 2014."

[57] Zhang, G., Zhang, H. (Nov 2008). "Adapative resource allocation for downlink OFDMA networks using cooperative game theory", In IEEE Communication Systems Signal International Conference. ICCS 2008. 11th IEEE Singapore International Conference on, pp. 98-103. IEEE, 2008..

[58] E. Yaacoub, and Z. Dawy. "A game theoretical formulation for proportional fairness in LTE uplink scheduling." 2009 IEEE Wireless Communications and Networking Conference. IEEE, 2009.

[59] Jing, Q. and Zheng, Z., "Distributed resource allocation based on game theory in multi-cell OFDMA systems." International Journal of Wireless Information Networks,2009 Jun 1;16(1-2):44-50.

[60] G. He, M. Debbah, and S. Lasaulce, "K-player bayesian waterfilling game for fading multiple access channels", Computational Advances in Multi-Sensor Adaptive Processing, 3rd IEEE International Workshop on, pp. 17-20, 2009.

[61] Ellenbeck, J., Al-Shatri, H. and Hartmann, C Lenbeck, "Performance of decentralized interference coordination in the LTE uplink" In : Vehicular Technology Conference Fall (VTC 2009-Fall), 2009 IEEE 70th. IEEE, 2009. p. 1-5.

[62] G. He, M. Debbah, and E. Altman, "A bayesian game-theoretic approach for distributed resource allocation in fading multiple access channels," EURASIP Journal on Wireless Communications and Networking, April 2010.

[63] L. Anchora, L. Canzian, L. Badia, M. Zorzi. A characterization of resource allocation in LTE systems aimed at game theoretical approaches, in:Proceedings of 15th International Workshop on Computer Aided Modeling, Analysis and Design of Communication Links and Networks (CAMAD), Dec 2010.

[64] Awada, A., Wegmann, B., Viering, I. and Klein, A, A game-theoretic approach to load balancing in cellular radio networks. In: 21st Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications. IEEE, 2010. p. 1184-1189.

[65] S.H. Paik, S. Kim and H.B. Park, "A resource allocation using game theory adopting AMC scheme in multi-cell OFDMA systems," 2010 2nd International Conference on Future Computer and Communication (ICFCC), vol. 2, pp. V2–344, May 2010.

[66] G. He, L. Cottatellucci, and M. Debbah. "The waterfilling game-theoretical framework for distributed wireless network information flow." EURASIP Journal on Wireless Communications and Networking 2010 Jul 20, no. 1 (2010): 1.

[67] S. Ali and M. Zeeshan, "A delay-scheduler coupled game theoretic resource allocation scheme for LTE networks," Frontiers of Information Technology (FIT), 2011.

[68] V. Stefanos, S. Armour, M. De Vos, and T. Lewis. "A distributed algorithm for wireless resource allocation using coalitions and the nash bargaining solution." In Vehicular Technology Conference (VTC Spring), 2011 IEEE 73rd, pp. 1-5. IEEE, 2011.

[69] V. Stefanos, S. Armour, M. De Vos, and T. Lewis. "A Fast and Fair Algorithm for Distributed Subcarrier Allocation Using Coalitions and the Nash Bargaining Solution." In Vehicular Technology Conference (VTC Fall), 2011 IEEE, pp. 1-5. IEEE, 2011.

[70] M. Haddad, S. Elayoubi, S. Altman, E. Et Al, "A hybrid approach for radio resource management in heterogeneous cognitive networks", IEEE Journal on Selected Areas in Communications, 2011, vol. 29, no 4, p. 831-842.

[71] Zhou, W., Xie, B. and Hao, C, "A novel bargaining based power allocation for Coordinated Multiple Point transmission/reception". In : Advanced Communication Technology (ICACT), 2011 13th International Conference on. IEEE, 2011. p. 458-462.

[72] A.Wang, Y. Cai, Z. Hou, "A Novel Resource Allocation Algorithm in Uplink Multi-cell OFDMA Networks Based on Game Theory", In Wireless Communications and Signal Processing (WCSP), 2011 International Conference on, pp. 1-4. IEEE, 2011.

[73] A. EL-HALABY, M. AWAD, "A game theoretic scenario for LTE load balancing"In : AFRICON, 2011. IEEE, 2011. p. 1-6.

[74] A. Khanafer, S. Bhattacharya, and T. Bas, "Adaptive resource allocation in jamming teams using game theory." Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (WiOpt), 2011 International Symposium on, pp. 395-400. IEEE, 2011.

[75] Huang, J.W. and Krishnamurthy, V, "Cognitive base stations in LTE/3GPP femtocells: A correlated equilibrium game-theoretic approach" IEEE Transactions on Communications, 2011, vol. 59, no 12, p. 3485-3493.

[76] Liu, S., Chang, Y., Yang, R. and Yang, D, Efficient Distributed Dynamic Resource Allocation for LTE Systems. In : Vehicular Technology Conference (VTC Fall), 2011 IEEE. IEEE, 2011. p. 1-5.

[77] Li, Z. and Li, S., "LTE network planning based on game theory", In : Computer Science and Service System (CSSS), 2011 International Conference on. IEEE, 2011. p. 3963-3966.

[78] Hou, Z., Cai, Y. and Wu, D, "Resource allocation based on integer programming and game theory in uplink multi-cell cooperative OFDMA systems", EURASIP Journal on Wireless Communications and Networking, 2011 Dec 1; 2011(1):1-0.

[79] M. Iturralde, T. A. Yahiya, A. Wei, and A. L. Beylot, "Resource allocation using Shapley value in LTE networks", in IEEE International Symposium on Personal Indoor and Mobile Radio Communications, 2011, pp. 31–35.

[80] G. He, S. Lasaulce, and Y. Hayel, "Stackelberg games for energy-efficient power control in wireless networks", In INFOCOM, Proceedings IEEE, pp. 591-595, 2011.

[81] Toseef, U., Khan, M.A., Görg, C. and Timm-Giel, A, "User satisfaction based resource allocation in future heterogeneous wireless networks", In : Communication Networks and Services Research Conference (CNSR), 2011 Ninth Annual. IEEE, 2011. p. 217-223.

[82] Alrabaee, S., Agarwal, A., Goel, N., Zaman, M. and Khasawneh, M., "A game theoretic approach to spectrum management in cognitive radio network." In Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT), 2012 4th International Congress on, pp. 906-913. IEEE, 2012.

[83] Chaabane, I.B., Hamouda, S, Tabbane, S, Vicario, J.L, "A new PRB sharing scheme in dual-hop LTE-advanced system using game theory", In 2012 IEEE 23rd International Symposium on Personal, Indoor and Mobile Radio Communications-(PIMRC), pp. 375-379. IEEE, 2012.

[84] Schroeder, D., El Essaili, A., Steinbach, E., Despotovic, Z. and Kellerer, W, "A quality-of-experience driven bidding game for uplink video transmission in next generation mobile networks", In : 2012 19th IEEE International Conference on Image Processing. IEEE, 2012. p. 2281-2284.

[85] M. Iturralde, T. A. Yahiya, A. Wei, and A. L. Beylot, A real-time services performance and interference mitigation for femtocell scenarios in LTE networks. In: Local Computer Networks (LCN), 2012 IEEE 37th Conference on. IEEE, 2012. p. 529-536.

[86] L. Liang, M. PESAVENTO, "A Game theoretical approach for spectrum sharing in cognitive radio systems with payoff perturbations", In: OFDM 2012, 17th International OFDM Workshop 2012 (InOWo'12); Proceedings of. VDE, 2012. p. 1-5.

[87] L. Militano, M. Condoluci, G. Araniti, Al. Bargaining solutions for multicast subgroup formation in LTE. In : Vehicular Technology Conference (VTC Fall), 2012 IEEE. IEEE, 2012. p. 1-5.

[88] T. Lin, T. Alpcan, K. Hinton, "Energy efficiency games for backhaul traffic in wireless networks", In : 2012 Conference Record of the Forty Sixth Asilomar Conference on Signals, Systems and Computers (ASILOMAR). IEEE, 2012. p. 666-670.

[89] C. Turyagyenda, T. O'farrell, W. Guo, "Energy efficient coordinated radio resource management: a two player sequential game modelling for the long-term evolution downlink", IET communications, 2012, vol. 6, no 14, p. 2239-2249.

[90] W. LI, H. ZHANG, W. ZHENG, et al,’’Energy-efficient power allocation with dual-utility in two-tier OFDMA femtocell networks. In : 2012 IEEE Globecom Workshops. IEEE, 2012. p. 535-540.

[91] G. P. Z, Y. L. Zhong, E. J. Ding,"Game Theoretic subcarrier and power allocation for wireless OFDMA networks" International Journal of Automation and Computing, August 2012, Volume 9, Issue 4, pp 414–419.

[92] S. FU, B. WU, P. HO, et al. "Interference coordination in CoMP with transmission scheduling and game theoretical power reallocation", In : 2012 IEEE International Conference on Communications (ICC). IEEE, 2012. p. 4212-4217.

[93] M. Iturralde, M, Yahiya, T. A, Wei, Anne, Et Al, Interference mitigation by dynamic self-power control in femtocell scenarios in LTE networks. In : Global Communications Conference (GLOBECOM), 2012 IEEE. IEEE, 2012. p. 4810-4815.

[94] S. Sardellitti, A. Carfagna, S. Barbarossa, "Optimal resource allocation in fetmocell networks based on Markov modeling of interferers' activity’’ EURASIP Journal on Wireless Communications and Networking,

[95] S. Buzzi, et al. "Potential games for energy-efficient power control and subcarrier allocation in uplink multicell OFDMA systems." IEEE Journal of Selected Topics in Signal Processing, 2012 Apr;6(2):89-103.

[96] L. ZHAO, C. ZHANG, H. ZHANG, et al. Power-efficient radio resource allocation for low-medium-altitude aerial platform based TD-LTE networks. In : Vehicular Technology Conference (VTC Fall), 2012 IEEE. IEEE, 2012. p. 1-5.

[97] L. ZHAO, YI. Liqiang, A. Jiangtao, Fumiyuki, et al. Radio resource allocation for low-medium-altitude aerial platform based TD-LTE networks against disaster. In : Vehicular Technology Conference (VTC Spring), 2012 IEEE 75th. IEEE, 2012. p. 1-5.

[98] M. Iturralde, A. Wei, T. A. Yahiya, A. L. Beylot,"Resource Allocation for Real Time Services in LTE Networks: Resource Allocation Using Cooperative Game Theory and Virtual Token Mechanism’’, Wireless Personal Communications September 2013, Volume 72, Issue 2, pp 1415–1435.

[99] S.M. Alavi, and Z. Chi,"Resource allocation scheme for orthogonal frequency division multiple access networks based on cooperative game theory." International Journal of Communication Systems, 2014 Aug 1;vol 27, no 8 :1105-25

[100] Y. Wang, W. Dongyao W, J.Y.Pang, and G. Shen, "Self-optimization of downlink transmission power in 3GPP LTE-A heterogeneous network", In Vehicular Technology Conference (VTC Fall), 2012 IEEE, pp. 1-5. IEEE, 2012.

[101] B. LIU, H.TIAN, A. Hui, "A bankruptcy game-based resource allocation approach among virtual mobile operators", IEEE Communications Letters, 2013, vol. 17, no 7, p. 1420-1423.

[102] I. N. Stiakogiannakis, D. I. Kaklamani ‘’A Radio Resource Management Framework for Multi-User Multi-Cell OFDMA Networks Based on Game Theory" Wireless Personal Communications, March 2013, Volume 69, Issue 2, pp 745–770.

[103] G. BACCI, L. Sanguinetti, M. Luise, Et al, " A game-theoretic approach for energy-efficient contention-based synchronization in OFDMA systems", IEEE Transactions on Signal Processing, 2013, vol. 61, no 5, p. 1258-1271.

[104] Kamel, Mahmoud I., and Khaled MF Elsayed. "ABSF offsetting and optimal resource partitioning for eICIC in LTE-Advanced: Proposal and analysis using a Nash bargaining approach." In 2013 IEEE International Conference on Communications (ICC), pp. 6240-6244. IEEE, 2013.

[105] Yang, Yufei, Tony QS Quek, and Lingjie Duan. "Backhaul-constrained optimization for hybrid access small cells." In 2013 IEEE International Conference on Acoustics, Speech and Signal Processing, pp. 4764-4768. IEEE, 2013.

[106] GHAREHSHIRAN, Omid Namvar, ATTAR, Alireza, et KRISHNAMURTHY, Vikram. Collaborative sub-channel allocation in cognitive LTE femto-cells: a cooperative game-theoretic approach. IEEE Transactions on Communications, 2013, vol. 61, no 1, p. 325-334.

[107] Singh, Chandramani K., and Chung Shue Chen. "Distributed downlink resource allocation in cellular networks through spatial adaptive play." In Teletraffic Congress (ITC), 2013 25th International, pp. 1-9. IEEE, 2013.

[108] Zhang, Rongqing, Lingyang Song, Zhu Han, Xiang Cheng, and Bingli Jiao. "Distributed resource allocation for device-to-device communications underlaying cellular networks." In 2013 IEEE International Conference on Communications (ICC), pp. 1889-1893. IEEE, 2013.

[109] AVRACHENKOV, Konstantin, COTTATELLUCCI, Laura, et MAGGI, Lorenzo. Dynamic rate allocation in Markovian quasi-static multiple access channels: A game theoretic approach. In : Modeling & Optimization in Mobile, Ad Hoc & Wireless Networks (WiOpt), 2013 11th International Symposium on. IEEE, 2013. p. 162-169.

[110] Xiao, Yong, Chau Yuen, Paolo Di Francesco, and Luiz A. DaSilva. "Dynamic spectrum scheduling for carrier aggregation: A game theoretic approach." In 2013 IEEE International Conference on Communications (ICC), pp. 2672-2676. IEEE, 2013.

[111] Xu, Chen, Lingyang Song, Zhu Han, Qun Zhao, Xiaoli Wang, Xiang Cheng, and Bingli Jiao. "Efficiency resource allocation for device-to-device underlay communication systems: a reverse iterative combinatorial auction based approach." IEEE Journal on Selected Areas in Communications 31, no. 9 (2013): 348-358.

[112] Al-Kanj, Lina, Zaher Dawy, Walid Saad, and Erhan Kutanoglu. "Energy-aware cooperative content distribution over wireless networks: Optimized and distributed approaches." IEEE transactions on vehicular technology 62, no. 8 (2013): 3828-3847.

[113] Wang, Feiran, Chen Xu, Lingyang Song, Qun Zhao, Xiaoli Wang, and Zhu Han. "Energy-aware resource allocation for device-to-device underlay communication." In 2013 IEEE International Conference on Communications (ICC), pp. 6076-6080. IEEE, 2013.

[114] D. G. Hernández, D. H. Zanette, Evolutionary Dynamics of Resource Allocation in the Colonel Blotto Game" Journal of Statistical Physics, May 2013, Volume 151, Issue 3, pp 623–636.

[115] Zhou, Liang, Min Chen, Yi Qian, and Hsiao-Hwa Chen. "Fairness resource allocation in blind wireless multimedia communications." IEEE Transactions on Multimedia 15, no. 4 (2013): 946-956.
[116] Lai, Wei-Sheng, Muh-En Chiang, Shen-Chung Lee, and Ta-Sung Lee. "Game theoretic distributed dynamic resource allocation with interference avoidance in cognitive femtocell networks." In 2013 IEEE wireless communications and networking conference (WCNC), pp. 3364-3369. IEEE, 2013.
[117] Sardellitti, Stefania, and Sergio Barbarossa. "Joint optimization of collaborative sensing and radio resource allocation in small-cell networks." IEEE Transactions on Signal Processing 61, no. 18 (2013): 4506-4520.
[118] Wang, Feiran, Lingyang Song, Zhu Han, Qun Zhao, and Xiaoli Wang. "Joint scheduling and resource allocation for device-to-device underlay communication." In 2013 IEEE Wireless Communications and Networking Conference (WCNC), pp. 134-139. IEEE, 2013.
[119] Militano, Leonardo, Massimo Condoluci, Giuseppe Araniti, and Antonio Iera. "Multicast service delivery solutions in LTE-Advanced systems." In 2013 IEEE International Conference on Communications (ICC), pp. 5954-5958. IEEE, 2013.
[120] Asadi, Arash, and Vincenzo Mancuso. "On the compound impact of opportunistic scheduling and D2D communications in cellular networks." In Proceedings of the 16th ACM international conference on Modeling, analysis & simulation of wireless and mobile systems, pp. 279-288. ACM, 2013.
[121] Gąsior, Dariusz, and Maciej Drwal. "Pareto-optimal Nash equilibrium in capacity allocation game for self-managed networks." Computer Networks 57, no. 14 (2013): 2817-2832.
[122] Yang, Yufei, Tony QS Quek, and Lingjie Duan. "Refunding for small cell networks with limited-capacity backhaul." In 2013 IEEE/CIC International Conference on Communications in China (ICCC), pp. 74-78. IEEE, 2013.
[123] Phunchongharn, Phond, Ekram Hossain, and Dong In Kim. "Resource allocation for device-to-device communications underlaying LTE-advanced networks." IEEE Wireless Communications 20, no. 4 (2013): 91-100.
[124] M. Iturralde, W. Anne, A. Y. Tara, André-Luc Beylot. "Resource Allocation for real time services in LTE networks: resource allocation using cooperative game theory and virtual token mechanism." Wireless personal communications 72, no. 2 (2013): 1415-1435.
[125] H. Xu, B. Li, "Resource allocation with flexible channel cooperation in cognitive radio networks." IEEE Transactions on Mobile Computing 12, no. 5 (2013): 957-970.
[126] Q. Han, K. Ma, X. C. Wang, X. Guan, J. Ma, "Stackelberg game based interference management for two-tier femtocell networks", Wireless Networks October 2013, Volume 19, Issue 7, pp 1665–1677.
[127] Wang, Chen, Yuan Liu, Meixia Tao, Zhu Han, and Dong In Kim. "Stackelberg game for spectrum reuse in the two-tier LTE femtocell network." In 2013 IEEE Wireless Communications and Networking Conference (WCNC), pp. 1888-1892. IEEE, 2013.
[128] Yu, Rong, Yan Zhang, Stein Gjessing, Wenlong Xia, and Kun Yang. "Toward cloud-based vehicular networks with efficient resource management." IEEE Network 27, no. 5 (2013): 48-55.
[129] Langar, Rami Et Pujolle, Guy. Tutorial 1: Radio resource management in small-cell networks. In : Ad Hoc Networking Workshop (MED-HOC-NET), 2013 12th Annual Mediterranean. IEEE, 2013. p. 1-2.
[130] Ling, Dabing, Zhaoming Lu, Ying Ju, Xiangming Wen, and Wei Zheng. "A multi-cell adaptive resource allocation scheme based on potential game for ICIC in LTE-A." International Journal of Communication Systems 27, no. 11 (2014): 2744-2761.
[131] Li, Yong, Depeng Jin, Jian Yuan, and Zhu Han. "Coalitional games for resource allocation in the device-to-device uplink underlaying cellular networks." IEEE Transactions on wireless communications 13, no. 7 (2014): 3965-3977.
[132] Zhang, Zengfeng, Lingyang Song, Zhu Han, and Walid Saad. "Coalitional games with overlapping coalitions for interference management in small cell networks." IEEE Transactions on Wireless Communications 13, no. 5 (2014): 2659-2669.
[133] ONU, Egena et ALANI, Omar. Collaborative algorithm for resource allocation in LTE-advanced relay networks. In : Communication Systems, Networks & Digital Signal Processing (CSNDSP), 2014 9th International Symposium on. IEEE, 2014. p. 938-942.
[134] Xu, Jing, Jiang Wang, Yuanping Zhu, Yang Yang, Xiaojin Zheng, Shuangdie Wang, Ligang Liu, Kari Horneman, and Yong Teng. "Cooperative distributed optimization for the hyper-dense small cell deployment." IEEE Communications Magazine 52, no. 5 (2014): 61-67.
[135] Zhou, Zhenyu, Mianxiong Dong, Kaoru Ota, Jun Wu, and Takuro Sato. "Distributed interference-aware energy-efficient resource allocation for device-to-device communications underlaying cellular networks." In 2014 IEEE Global Communications Conference, pp. 4454-4459. IEEE, 2014.
[136] Chen, Xue, Rose Qingyang Hu, and Yi Qian. "Distributed resource and power allocation for device-to-device communications underlaying cellular network." In 2014 IEEE Global Communications Conference, pp. 4947-4952. IEEE, 2014.
[137] Loumiotis, Ioannis V., Evgenia F. Adamopoulou, Konstantinos P. Demestichas, Theodora A. Stamatiadi, and Michael E. Theologou. "Dynamic backhaul resource allocation: An evolutionary game theoretic approach." IEEE Transactions on Communications 62, no. 2 (2014): 691-698.
[138] Bourdena, Athina, Evangelos Pallis, Georgios Kormentzas, and George Mastorakis. "Efficient radio resource management algorithms in opportunistic cognitive radio networks." Transactions on emerging telecommunications technologies 25, no. 8 (2014): 785-797.
[139] Liu, Gang, Hong Ji, F. Richard Yu, Yi Li, and Renchao Xie. "Energy-efficient resource allocation in full-duplex relaying networks." In 2014 IEEE International Conference on Communications (ICC), pp. 2400-2405. IEEE, 2014.
[140] Wu, Dan, Jinlong Wang, Rose Qingyang Hu, Yueming Cai, and Liang Zhou. "Energy-efficient resource sharing for mobile device-to-device multimedia communications." IEEE Transactions on Vehicular Technology 63, no. 5 (2014): 2093-2103.
[141] Lin, Jia-Shi, and Kai-Ten Feng. "Femtocell access strategies in heterogeneous networks using a game theoretical framework." IEEE transactions on wireless communications 13, no. 3 (2014): 1208-1221.
[142] Zhao, Jun, Wei Zheng, Xiangming Wen, Xiaoli Chu, Haijun Zhang, and Zhaoming Lu. "Game theory based energy-aware uplink resource allocation in OFDMA femtocell networks." International Journal of Distributed Sensor Networks 2014 (2014).
[143] Khawam, Kinda, ADOUANE, Amine, LAHOUD, Samer, et al. Game theoretic framework for power control in intercell interference coordination. In : Networking Conference, 2014 IFIP. IEEE, 2014. p. 1-8.
[144] Wang, Yuanshuang, Miao, Guowang, Et Wang, Xia. Joint Interference Mitigation and Power Allocation for Multi-Cell LTE Networks: A Non-Cooperative Game Approach. In : 2014 IEEE 80th Vehicular Technology Conference (VTC2014-Fall). IEEE, 2014. p. 1-6.
[145] PANG, Yuan-Chi, CHAO, Shih-Lung, LIN, Guan-Yu, et al. Network access for M2M/H2H hybrid systems: a game theoretic approach. IEEE Communications Letters, 2014, vol. 18, no 5, p. 845-848.
[146] Zheng, Jianchao, Yueming Cai, Yongkang Liu, Yuhua Xu, Bowen Duan, and Xuemin Sherman Shen. "Optimal power allocation and user scheduling in multicell networks: Base station cooperation using a game-theoretic approach." IEEE Transactions on Wireless Communications 13, no. 12 (2014): 6928-6942.
[147] HE, Yinuo, LUAN, Xi, WANG, Jiajia, et al. Power allocation for D2D communications in heterogeneous networks. In : 16th

International Conference on Advanced Communication Technology. IEEE, 2014. p. 1041-1044.

[148] ADOUANE, Amine, KHAWAM, Kinda, COHEN, Johanne, et al. Replicator dynamics for distributed inter-cell interference coordination. In : 2014 IEEE Symposium on Computers and Communications (ISCC). IEEE, 2014. p. 1-7.

[149] Huang, Jun, Yanxiao Zhao, and Kazem Sohraby. "Resource allocation for intercell device-to-device communication underlaying cellular network: A game-theoretic approach." In 2014 23rd International Conference on Computer Communication and Networks (ICCCN), pp. 1-8. IEEE, 2014.

[150] XIA, Chunmei, XU, Shaoyi, et KWAK, Kyung Sup. Resource allocation for device-to-device communication in LTE-A network: A stackelberg game approach. In : 2014 IEEE 80th Vehicular Technology Conference (VTC2014-Fall). IEEE, 2014. p. 1-5.

[151] HUANG, Bo-Yuan, SU, Shih-Tang, WANG, Chih-Yu, et al. Resource allocation in D2D communication-A game theoretic approach. In : 2014 IEEE International Conference on Communications Workshops (ICC). IEEE, 2014. p. 483-488.

[152] DU, Jintao et ZHAO, Jihong. RRM strategy based on throughput and fairness in LTE-A relay system. In : 16th International Conference on Advanced Communication Technology. IEEE, 2014. p. 1059-1064.

[153] FU, Shu, WU, Bin, WEN, Hong, et al. Transmission scheduling and game theoretical power allocation for interference coordination in CoMP. IEEE Transactions on Wireless Communications, 2014, vol. 13, no 1, p. 112-123.

[154] Ashidani, Pedro Junior, and Paulo Roberto Guardieiro. "Two-level downlink Resource Allocation Scheme based on cooperative game theory in LTE networks." In 2014 Nov 12, IFIP Wireless Days (WD), pp. 1-4. IEEE, 2014.

[155] HAMOUDA, Soumaya, ZITOUN, Monia, et TABBANE, Sami. Win–win relationship between macrocell and femtocells for spectrum sharing in LTE-A. IET Communications, 2014, vol. 8, no 7, p. 1109-1116.

[156] SHENG, Min, YANG, Chungang, ZHANG, Yan, et al. Zone-based load balancing in LTE self-optimizing networks: a game-theoretic approach. IEEE Transactions on Vehicular Technology, 2014, vol. 63, no 6, p. 2916-2925.

[157] Xu, Ke, Kuang-Ching Wang, Rahul Amin, Jim Martin, and Ryan Izard. "A fast cloud-based network selection scheme using coalition formation games in vehicular networks." IEEE Transactions on Vehicular Technology 64, no. 11 (2015): 5327-5339.

[158] Cai, Yueming, Jianchao Zheng, Yi Wei, Yuhua Xu, and Alagan Anpalagan. "A joint game-theoretic interference coordination approach in uplink multi-cell OFDMA networks." Wireless Personal Communications 80, no. 3 (2015): 1203-1215.

[159] HAJJAWI, Ayman, ISMAIL, Mahamod, ABDULLAH, Nor Fadzilah, et al. A novel scheduling algorithm based class-service using game theory for LTE network. In : Communications (MICC), 2015 IEEE 12th Malaysia International Conference on. IEEE, 2016. p. 351-355.

[160] SODAGARI, Shabnam. A Secure Radio Environment Map Database to Share Spectrum. IEEE Journal of Selected Topics in Signal Processing, 2015, vol. 9, no 7, p. 1298-1305.

[161] Maaz, Bilal, Kinda Khawam, and Samir Tohme. "Achieving spectral and energy efficiencies in multi-cell networks." In Innovations in Information Technology (IIT), 2015 11th International Conference on, pp. 98-103. IEEE, 2015.

[162] Semasinghe, Prabodini, Ekram Hossain, and Kun Zhu. "An evolutionary game for distributed resource allocation in self-organizing small cells." IEEE Transactions on Mobile Computing 14, no. 2 (2015): 274-287.

[163] Langar, Rami, Stefano Secci, Raouf Boutaba, and Guy Pujolle. "An operations research game approach for resource and power allocation in cooperative femtocell networks." IEEE Transactions on Mobile Computing 14, no. 4 (2015): 675-687.

[164] Peng, Mugen, Xinqian Xie, Qiang Hu, Jie Zhang, and H. Vincent Poor. "Contract-based interference coordination in heterogeneous cloud radio access networks." IEEE Journal on Selected Areas in Communications 33, no. 6 (2015): 1140-1153.

[165] Ye, Qiaoyang, Mazin Al-Shalash, Constantine Caramanis, and Jeffrey G. Andrews. "Distributed resource allocation in device-to-device enhanced cellular networks." IEEE Transactions on Communications 63, no. 2 (2015): 441-454.

[166] Xu, Chao, Min Sheng, Xijun Wang, Cheng-Xiang Wang, and Jiandong Li. "Distributed subchannel allocation for interference mitigation in OFDMA femtocells: A utility-based learning approach." IEEE Transactions on Vehicular Technology 64, no. 6 (2015): 2463-2475.

[167] Chen, Xue, Rose Qingyang Hu, Jeongho Jeon, and Geng Wu. "Energy efficient resource allocation for D2D communication underlaying cellular networks." In 2015 IEEE International Conference on Communications (ICC), pp. 2943-2948. IEEE, 2015.

[168] Bacci, Giacomo, E. Veronica Belmega, Panayotis Mertikopoulos, and Luca Sanguinetti. "Energy-aware competitive power allocation for heterogeneous networks under QoS constraints." IEEE Transactions on Wireless Communications 14, no. 9 (2015): 4728-4742.

[169] Hoang, Tuong Duc, Long Bao Le, and Tho Le-Ngoc. "Energy-efficient resource allocation for D2D communications in cellular networks." In 2015 IEEE International Conference on Communications (ICC), pp. 2251-2256. IEEE, 2015.

[170] Wang, Feiran, Chen Xu, Lingyang Song, and Zhu Han. "Energy-efficient resource allocation for device-to-device underlay communication." IEEE Transactions on Wireless Communications 14, no. 4 (2015): 2082-2092.

[171] CHEN, Qimei, YU, Guanding, YIN, Rui, et al. Energy-efficient resource block allocation for licensed-assisted access. In : Personal, Indoor, and Mobile Radio Communications (PIMRC), 2015 IEEE 26th Annual International Symposium on. IEEE, 2015. p. 1018-1023.

[172] Al-Imari, Mohammed, et al. "Game theory based radio resource allocation for full-duplex systems." 2015 IEEE 81st Vehicular Technology Conference (VTC Spring). pp. 1-5. IEEE, May, 2015.

[173] FAN, Bo, TIAN, Hui, et LIU, Bin. Game theory based power allocation in LTE air interface virtualization. In : 2015 IEEE Wireless Communications and Networking Conference (WCNC). IEEE, 2015. p. 972-976.

[174] Zhou, Zhenyu, Mianxiong Dong, Kaoru Ota, Ruifeng Shi, Zhiheng Liu, and Takuro Sato. "Game-theoretic approach to energy-efficient resource allocation in device-to-device underlay communications." IET Communications 9, no. 3 (2015): 375-385.

[175] Liang, Liang, Gang Feng, and Yunjian Jia. "Game-theoretic hierarchical resource allocation for heterogeneous relay networks." IEEE Transactions on Vehicular Technology 64, no. 4 (2015): 1480-1492.

[176] Ma, Bojiang, Man Hon Cheung, Vincent WS Wong, and Jianwei Huang. "Hybrid overlay/underlay cognitive femtocell networks: A game theoretic approach." IEEE Transactions on Wireless Communications 14, no. 6 (2015): 3259-3270.

[177] Li, Peng, and Song Guo. "Incentive mechanisms for device-to-device communications." IEEE Network 29, no. 4 (2015): 75-79.

[178] MAAZ, Bilal, KHAWAM, Kinda, TOHME, Samir, et al. Inter-cell interference coordination based on power control for self-organized 4G systems. In : Digital Information and Communication Technology and its Applications (DICTAP), 2015 Fifth International Conference on. IEEE, 2015. p. 149-154.

[179] AKKARAJITSAKUL, Khajonpong et PHUNCHONGHARN, Phond. Joint cell selection and subchannel allocation for energy efficiency in small cell networks: A coalitional game. In : Wireless Communications & Signal Processing (WCSP), 2015 International Conference on. IEEE, 2015. p. 1-6.

[180] Zhu, Kun, and Ekram Hossain. "Joint mode selection and spectrum partitioning for device-to-device communication: A dynamic stackelberg game." IEEE Transactions on Wireless Communications 14, no. 3 (2015): 1406-1420.
[181] Zhao, Yulei, Yong Li, Xiang Chen, and Ning Ge. "Joint optimization of resource allocation and relay selection for network coding aided device-to-device communications." IEEE Communications Letters 19, no. 5 (2015): 807-810.
[182] Zhong, Wei, Yixin Fang, Shi Jin, Kai-Kit Wong, Sheng Zhong, and Zuping Qian. "Joint resource allocation for device-to-device communications underlaying uplink MIMO cellular networks." IEEE Journal on Selected Areas in Communications 33, no. 1 (2015): 41-54.
[183] MAAZ, Bilal, KHAWAM, Kinda, TOHME, Samir, et al. Joint scheduling and power control in multi-cell networks for inter-cell interference coordination. In : Wireless and Mobile Computing, Networking and Communications (WiMob), 2015 IEEE 11th International Conference on. IEEE, 2015. p. 778-785.
[184] Pandian, Mani Bharathi, Mihail L. Sichitiu, and Huaiyu Dai. "Optimal resource allocation in random access cooperative cognitive radio networks." IEEE Transactions on Mobile Computing 14, no. 6 (2015): 1245-1258.
[185] Chen, Yichao, Shibo He, Fen Hou, Zhiguo Shi, and Xu Chen. "Optimal user-centric relay assisted device-to-device communications: an auction approach." IET Communications 9, no. 3 (2015): 386-395.
[186] ALAM, M. Jawad et MA, Maode. Pareto efficient resource matching for LTE-A system. In : 2015 10th International Conference on Information, Communications and Signal Processing (ICICS). IEEE, 2015. p. 1-5.
[187] Kumar, Neeraj, Sherali Zeadally, Naveen Chilamkurti, and Alexey Vinel. "Performance analysis of Bayesian coalition game-based energy-aware virtual machine migration in vehicular mobile cloud." IEEE Network 29, no. 2 (2015): 62-69.
[188] An, Chunyan, Renchao Xie, Hong Ji, and Yi Li. "Pricing and power control for energy-efficient radio resource management in cognitive femtocell networks." International Journal of Communication Systems 28, no. 4 (2015): 743-761.
[189] Yin, Rui, Guanding Yu, Huazi Zhang, Zhaoyang Zhang, and Geoffrey Ye Li. "Pricing-based interference coordination for D2D communications in cellular networks." IEEE Transactions on Wireless Communications 14, no. 3 (2015): 1519-1532.
[190] Wang, Qin, Wei Wang, Shi Jin, Hongbo Zhu, and Nai Tong Zhang. "Quality-optimized joint source selection and power control for wireless multimedia D2D communication using stackelberg game." IEEE Transactions on Vehicular Technology 64, no. 8 (2015): 3755-3769.
[191] Al-Imari, Mohammed, Mir Ghoraishi, and Pei Xiao. "Radio resource allocation and system-level evaluation for full-duplex systems." In Computer Aided Modelling and Design of Communication Links and Networks (CAMAD), 2015 IEEE 20th International Workshop on, pp. 103-107. IEEE, 2015.
[192] Zhang, Haijun, Chunxiao Jiang, Norman C. Beaulieu, Xiaoli Chu, Xianbin Wang, and Tony QS Quek. "Resource allocation for cognitive small cell networks: A cooperative bargaining game theoretic approach." IEEE Transactions on Wireless Communications 14, no. 6 (2015): 3481-3493.
[193] Onu, Egena, and Omar Alani. "Resource allocation in LTE-Advanced network: A collaborative market game approach." In Computer Science and Electronic Engineering Conference (CEEC), 2015 7th, pp. 99-104. IEEE, 2015.
[194] Liu, Tanhui, and Gang Wang. "Resource allocation for device-to-device communications as an underlay using nash bargaining game theory." Information and Communication Technology Convergence (ICTC), 2015 International Conference on 2015 Oct 28 (pp. 366-371). IEEE.
[195] HOLFELD, Bernd, JAEUTHE, Tobias, et WIRTH, Thomas. Resource Sharing with Minimum QoS Requirements for D2D Links Underlaying Cellular Networks. In : 2015 IEEE 81st Vehicular Technology Conference (VTC Spring). IEEE, 2015. p. 1-7.
[196] Ko, Chun-Han, Ching-Chun Chou, Hsiang-Yun Meng, and Hung-Yu Wei. "Strategy-proof resource allocation mechanism for multi-flow wireless multicast." IEEE Transactions on Wireless Communications 14, no. 6 (2015): 3143-3156.
[197] LIU, Yanping, FANG, Xuming, YANG, Huali, et al. A Mapping Scheme of Users to SCMA Layers for D2D Communications. In : Vehicular Technology Conference (VTC Spring), 2016 IEEE 83rd. IEEE, 2016. p. 1-5.
[198] HUANG, Fan, VÈQUE, Véronique, et TOMASIK, Joanna. A Pareto-optimal Approach for Resource Allocation on the LTE downlink. In : International Conference on Communications (ICC). 2016.
[199] Yuan, Shitong, and Qilian Liang. "Cooperative Bandwidth Sharing for 5G Heterogeneous Network Using Game Theory." In Networking, Architecture and Storage (NAS), 2016 IEEE International Conference on, pp. 1-6. IEEE, 2016.
[200] Trabelsi, Nessrine, Chung Shue Chen, Laurent Roullet, Eitan Altman, and Rachid El-Azouzi. "Coordinated scheduling via Frequency and Power Allocation Optimization in LTE Cellular Networks." In IEEE/IFIP Network Operations and Management Symposium. 2016.
[201] Wang, Chih-Yu, Guan-Yu Lin, Ching-Chun Chou, Che-Wei Yeh, and Hung-Yu Wei. "Device-to-Device Communication in LTE-Advanced System: A Strategy-proof Resource Exchange Framework." (2016).
[202] Kaliski, Rafael, and Hung-Yu Wei. "Dynamic Resource Allocation and Advertisement Revenue Optimization for TV Over eMBMS."Institute of Electrical and Electronics Engineers,IEEE Transactions on Broadcasting,2016
[203] CHEN, Mingzhe, SAAD, Walid, et YIN, Changchuan. Echo State Networks for Self-Organizing Resource Allocation in LTE-U with Uplink-Downlink Decoupling. arXiv preprint arXiv:1601.06895, 2016.
[204] Zhou, Zhenyu, Mianxiong Dong, Kaoru Ota, Guojun Wang, and Laurence T. Yang. "Energy-Efficient Resource Allocation for D2D Communications Underlaying Cloud-RAN-Based LTE-A Networks." IEEE Internet of Things Journal 3, no. 3 (2016): 428-438.
[205] Schroeder, D., El Essaili, A., & Steinbach, E. “Fast converging auction-based resource allocation for QoE-driven wireless video streaming’’, In Communications Workshops (ICC), 2016 IEEE International Conference on, pp. 540-546. IEEE, 2016
[206] Zhang, R., Wang, M., Shen, X. and Xie, L.L, Probabilistic Analysis on QoS Provisioning for Internet of Things in LTE-A Heterogeneous Networks with Partial Spectrum Usage. IEEE Internet of Things Journal, 2016, vol. 3, no 3, p. 354-365.
[207] Su, S. T., Huang, B. Y., Wang, C. Y., Yeh, C. W., & Wei, H. Y, “Protocol Design and Game Theoretic Solutions for Device-to-Device Radio Resource Allocation”, IEEE Transactions on Vehicular Technology, 2016.
[208] G. Wang, T. H. Liu, ‘’Resource allocation for M2M-enabled cellular network using Nash bargaining game theory", Peer-to-Peer Networking and Applications, pp 1–14, 2016
[209] Samia, D., Ridha, B. and Wei, A, "Resource allocation using Nucleolus Value in downlink LTE networks." In Computers and Communication (ISCC), 2016 IEEE Symposium on, pp. 250-254. IEEE, 2016.
[210] Wang, C.Y., Wei, H.Y. and Chen, W.T, “Resource Block Allocation with Carrier-Aggregation: A Strategy-Proof Auction Design. *IEEE Transactions on Mobile Computing* 15, no. 12 (2016): 3142-3155.
[211] CHEN, Q., Yu, G., Maaref, A., Li, G. Y., & Huang, A. "Rethinking mobile data offloading for LTE in unlicensed spectrum." IEEE Transactions on Wireless Communications 15, no. 7 (2016): 4987-5000.

[212] Chen, Q., Yu, G., Maaref, A., Li, G.Y. and Huang, A, Rethinking mobile data offloading in LTE and WiFi coexisting systems. In : Wireless Communications and Networking Conference (WCNC), 2016 IEEE. IEEE, 2016. p. 1-6.

[213] Zhao, J., Chai, K.K., Chen, Y., Schormans, J. and Alonso-Zarate, J. "Two-level game for relay-based throughput enhancement via D2D communications in LTE networks." In Communications (ICC), 2016 IEEE International Conference on, pp. 1-6. IEEE, 2016.

[214] Grassi, A., Piro, G., Bacci, G. and Boggia, G., "Uplink resource management in 5G: when a distributed and energy-efficient solution meets power and QoS constraints". IEEE Transactions on Vehicular Technology, 2016.

[215] GAO, L., Li, P., Pan, Z., Liu, N. and You, X., "Virtualization Framework and VCG Based Resource Block Allocation Scheme for LTE Virtualization". In: Vehicular Technology Conference (VTC Spring), 83rd. IEEE, 2016. p. 1-6.

[216] L. Cottatellucci, LCSAS2014, Game Theory and Telecommunication, "Game Theoretical Methods for Resource Allocation at the Physical Layer ", Italia,12 September 2014

[217] Z. HOU, D. WU, Y. Cai, "Subcarrier and Power Allocation in Uplink Multi-cell OFDMA Systems Based on Game Theory", In: Proc IEEE ICNNSP, Zhenjiang, China, 2008, 522–526.

[218] N. Leibowitz, B. Baum, G. Enden, A. Karniel, "The exponential learning equation as a function of successful trials results in sigmoid performance", Journal of Mathematical Psychology Volume 54, Issue 3, June 2010, Pages 338-340.

[219] M. Gidlund and J.-C. Laneri, "Scheduling algorithms for 3gpp long-term evolution systems: From a quality of service perspective," Proceedings of the 10th IEEE International Symposium on Spread Spectrum Tech- niques and Applications (ISSSTA 08), pp. 114–117, August 2008.

[220] R. Basukala, H. M. Ramli, and K. Sandrasegaran, "Performance analysis of exp/pf and m-lwdf in downlink 3gpp lte system," Proc.of First Asian Himalayas International Conference on Internet, AH-ICI, Kathmandu,Nepal, November 2009.

[221] J.-G. Choi and S. Bahk, "Cell-throughput analysis of the proportional fair scheduler in the single-cell environment," IEEE Transactions on Vehicular Technologies, vol. 52, pp. 766–778, March 2007.

[222] Sadiq, B., Madan, R., & Sampath, A "Downlink scheduling for multiclass traffic in LTE." EURASIP Journal on Wireless Communications and Networking 2009, no. 1 (2009): 510617.

[223] Radio Access and Spectrum (RAS), "5G radio network architecture, "Radio Access and Spectrum FP7-Future Networks Cluster, Available from: http://www.ict-ras.eu/ accessed 08 December 2014.

[224] Ge, X., Tu, S., Mao, G., Wang, C. X., & Han, T, "5G ultra-dense cellular networks." IEEE Wireless Communications 23, no. 1 (Feb 2016): 72-79.

[225] T.S. Rappaport, S. Sun, R. Mayzus, H. Zhao et al., "Millimeter wave mobile communications for 5G cellular: it will work!," IEEE Access, vol.1, pp. 335–349, 2013.

[226] E.G. Larsson, O. Edfors, F. Tufvesson, T.L. Marzetta, "Massive MIMO for next generation wireless systems," IEEE Commun. Mag., February 2014, pp. 186–195.

[227] X. Lu, P. Wang, D. Niyato, D. Kim, and Z. Han, "Wireless networks with RF energy harvesting: A contemporary survey, IEEE Communications Surveys & Tutorials, pp. 1-29, 5 Sep. 2014.

[228] E. Hossain, M. Rasti, H. Tabassum and A. Abdelnasser, "Evolution towards 5G multi-tier cellular wireless networks: an interference management perspective," IEEE Wireless Commun., pp. 118–127, June 2014.

[229] Liu, Jiajia, H. Guo, H. Nishiyama, H. Ujikawa, K. Suzuki, and Nei Kato. "New Perspectives on Future Smart FiWi Networks: Scalability, Reliability, and Energy Efficiency." IEEE Communications Surveys & Tutorials 18, no. 2 (2016): 1045-1072.

[230] Simsek, M., Aijaz, A., Dohler, M., Sachs, J., & Fettweis, G, "5G-enabled tactile internet." IEEE Journal on Selected Areas in Communications 34, no. 3 (2016): 460-473.

[231] A. Aijaz, Dohler, M., Aghvami, A. H., Friderikos, V., Frodigh, M, "Realizing the tactile internet: Haptic communications over next generation 5g cellular networks." arXiv preprint arXiv:1510.02826 (2015).

[232] Orakzai, F. A., Iqbal, M., Ahmad, A., & Naeem, M., "A compendium of optimization techniques for green radio resource management." Telecommunication Systems (2017): 1-22

[233] Magalhães, J. M. H., da Mata, S. H., & Guardieiro, P. R."Downlink and Uplink Resource Allocation in LTE Networks." Handbook of Research on Next Generation Mobile Communication Systems (2015): 199.

[234] Xie, H., Wang, B., Gao, F., & Jin, S. "A Full-Space Spectrum-Sharing Strategy for Massive MIMO Cognitive Radio Systems." IEEE Journal on Selected Areas in Communications 34, no. 10 (2016): 2537-2549.

[235] Li, J., Wang, X., Feng, D., Sheng, M., & Quek, T. Q "Share in the Commons: Coexistence between LTE Unlicensed and Wi-Fi." IEEE Wireless Communications 23, no. 6 (2016): 16-23.

[236] Chen, Q., Yu, G., Ding, Z. "Optimizing Unlicensed Spectrum Sharing for LTE-U and WiFi Network Coexistence." IEEE Journal on Selected Areas in Communications 34, no. 10 (2016): 2562-2574.

[237] Giannoulakis, I., Kafetzakis, E., Kourtis, A. "Device-to-Device Communications." Handbook of Research on Next Generation Mobile Communication Systems (2015): 234.

[238] Nam, W., Bai, D., Lee, J., Kang, I. "Advanced interference management for 5G cellular networks." IEEE Communications Magazine 52, no. 5 (2014): 52-60.

[239] S. Guruacharya, D. Niyato, M. Bennis and D.I. Kim, "Dynamic coalition formation for network MIMO in small cell networks," IEEE Trans.Wireless Commun., vol. 12, no. 10, pp. 5360–5372, 2013.

[240] T.Zhou, Y. Chen, and K. Liu, "Network formation games in cooperative MIMO interference systems," IEEE Trans. Wireless Commun., vol. 13, no. 2, pp. 1140–1152, 2014.

[241] Jungnickel, V., Manolakis, K., Zirwas, W., Panzner, B., Braun, V., Lossow, M., Sternad, M., Apelfrojd, R. and Svensson, T., "The role of small cells, coordinated multipoint, and massive MIMO in 5G." IEEE Communications Magazine 52, no. 5 (2014): 44-51.

[242] R. Mochaourab and E.A. Jorswieck, "Coalitional games in MISO interference channels: epsilon-core and coalition structure stable set,"IEEE Trans. Signal Process., vol. 62, no. 24, pp. 6507–6520, 2014.

[243] Bassoy, S., Jaber, M., Imran, M.A. and Xiao, P., "Load aware self-organising user-centric dynamic CoMP clustering for 5G networks." IEEE Access 4 (2016): 2895-2906.

[244] Brandt, R., Mochaourab, R. and Bengtsson, M., "Distributed long-term base station clustering in cellular networks using coalition formation." IEEE Transactions on Signal and Information Processing over Networks 2, no. 3 (2016): 362-375.

[245] M. R. Akdeniz and S. Rangan, "Optimal Wireless Scheduling with Interference Cancellation," Proc. IEEE Intl. Symp. Info. Theory, Istanbul, Turkey, pp. 246-50, July 2013

[246] E. Hossain and M. Hasan, "5G cellular: key enabling technologies and research challenges," Submitted on 16 February 2015, IEEE Instrumentation and Measurement Mag., 2015.

[247] L. M. Corts-Pea, and D. M. Blough, "Distributed MIMO Interference Cancellation for Interfering Wireless Networks: Protocol and Initial Simulations," Technical Report GIT-CERCS-13-02, 2013. (also available at http://www.cercs.gatech.edu/techreports/)

[248] Adhikary, J. Nam, J.-Y. Ahn, and G. Caire, "Joint spatial division and multiplexing: The large-scale array regime," IEEE Trans. on Inf. Theory, vol. 59, no. 10, pp. 6441–6463, 2013.

[249] S. Hur, T. Kim, D.J. Love, J. V. Krogmeier, T.A. Thomas and A.Ghosh, "Millimeter wave beamforming for wireless backhaul and access in smallcell networks," IEEE Trans. Commun., vol. 61, no. 10, pp. 4391–4403, October 2013.

[250] H. Lee, S. Vahid, K. Moessner, "A Survey of radio resource management for spectrum aggregation in LTE-Advanced," vol. 16, no. 2, pp. 745–760, 2014

[251] Razavizadeh, S.M., Ahn, M. and Lee, I.,"Three-dimensional beamforming: A new enabling technology for 5G wireless networks." IEEE Signal Processing Magazine 31, no. 6 (2014): 94-101.

[252] Roh, W., Seol, J.Y., Park, J., Lee, B., Lee, J., Kim, Y., Cho, J., Cheun, K. and Aryanfar, F, "Millimeter-wave beamforming as

an enabling technology for 5G cellular communications: theoretical feasibility and prototype results." IEEE Communications Magazine 52, no. 2 (2014): 106-113.

[253] Andrews, J.G., Buzzi, S., Choi, W., Hanly, S.V., Lozano, A., Soong, A.C. and Zhang, J.C., "What will 5G be?." IEEE Journal on selected areas in communications 32, no. 6 (2014): 1065-1082.

[254] G. Lee and Y. Sung, “A new approach to user scheduling in massive multi-user MIMO broadcast channels,” IEEE Trans. Info. Theory, vol.1, no. 2014, pp. 1–43. Mar. 2014.